Unit 1: Introduction

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1. Introduction to Computer Graphics

- The computer graphics is one of the most effective and commonly used way to communicate the processed information to the user.
- It displays the information is the form of graphics objects such as pictures, charts, graphs and diagrams instead of simple text.
- The processing of geometric primitive with pixel level in an image or graphical image.
- In computer graphics, pictures or graphics objects are presented as a collection of discrete picture elements called pixels.

Applications of Computer Graphics

- User Interfaces
- Plotting of graphics and chart
- Office automation and Desktop publishing
- Computer-aided drafting and design
- Simulation and Animation
- Art and Commerce
- Process Control
- Cartography

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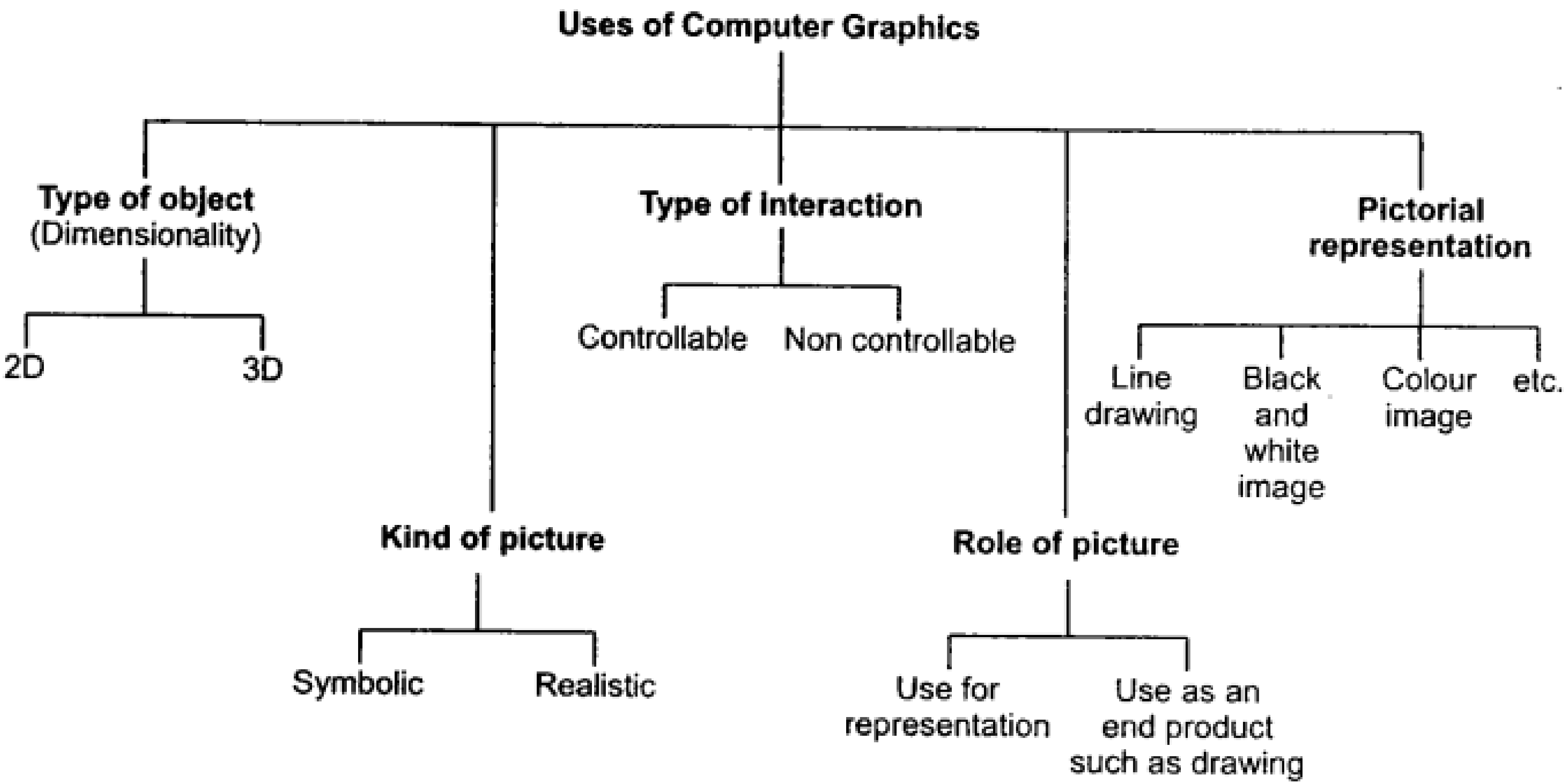
Classification of CG Applications



2. Video Display Devices

- Typically, the primary output device in a graphics system is a video monitor.

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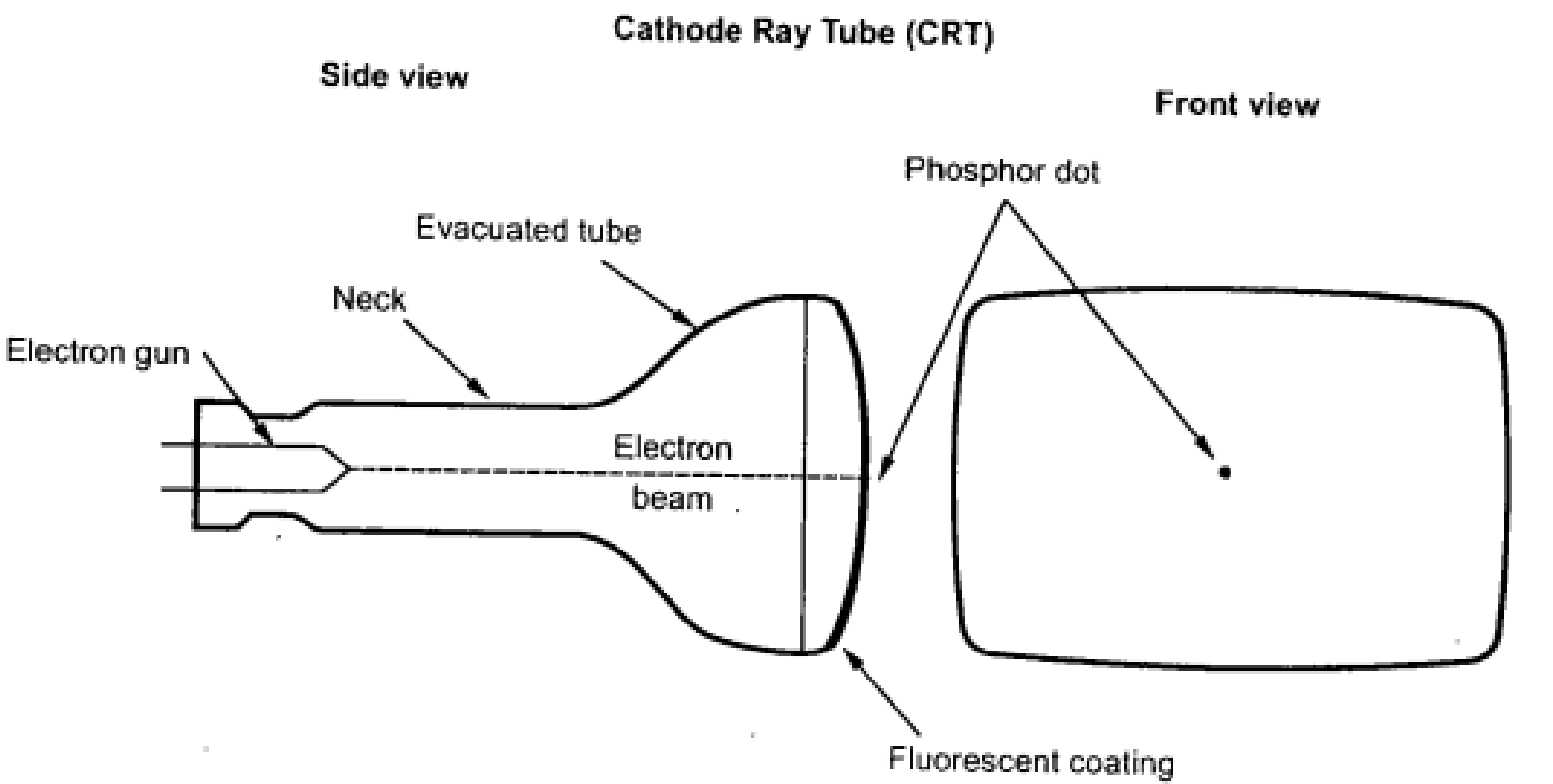
- The operation of most video monitors is based on the standard **Cathode-Ray Tube (CRT)** design.

Cathode-Ray Tube (CRT)

- A beam of electrons (cathode rays), emitted by an electron gun, passes through focusing and deflection systems that direct the beam toward specified positions on the phosphor-coated screen.
- The phosphor then emits a small spot of light at each position contacted by the electron beam.
- Because the light emitted by the phosphor fades very rapidly, some method is needed for maintaining the screen picture.

- One way to do this is to store the picture information as a charge distribution within the CRT.
- This charge distribution can then be used to keep the phosphors activated.
- However, the most common method now employed for maintaining phosphor glow is to redraw the picture repeatedly by quickly directing the electron beam back over the same screen points.
- This type of display is called a refresh CRT, and the frequency at which a picture is redrawn on the screen is referred to as the refresh rate.

Cathode-Ray Tube (CRT)…



Cathode-Ray Tube (CRT)…

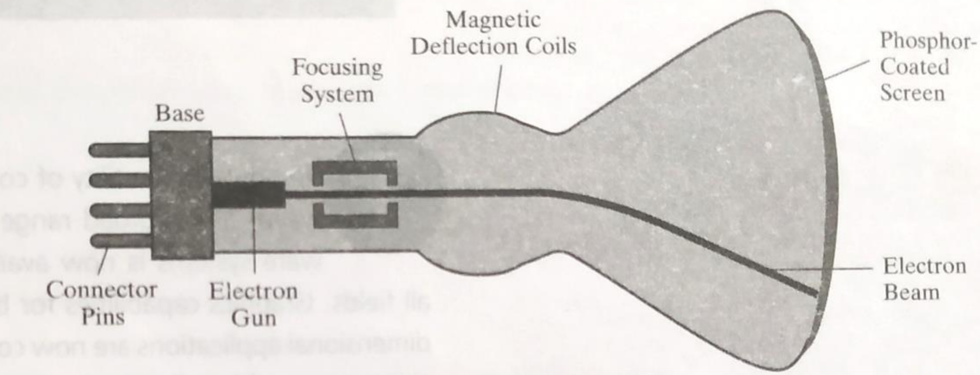


FIGURE 1
Basic design of a magnetic-deflection CRT.

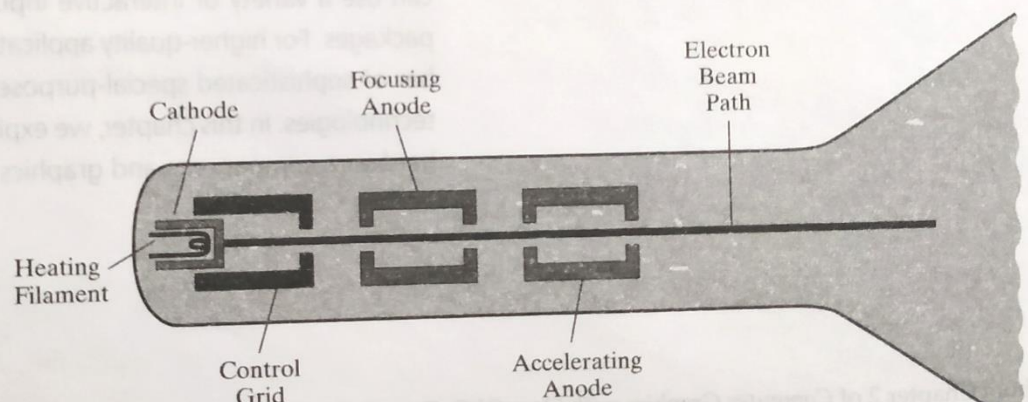


FIGURE 2
Operation of an electron gun with an accelerating anode.

Cathode-Ray Tube (CRT)…

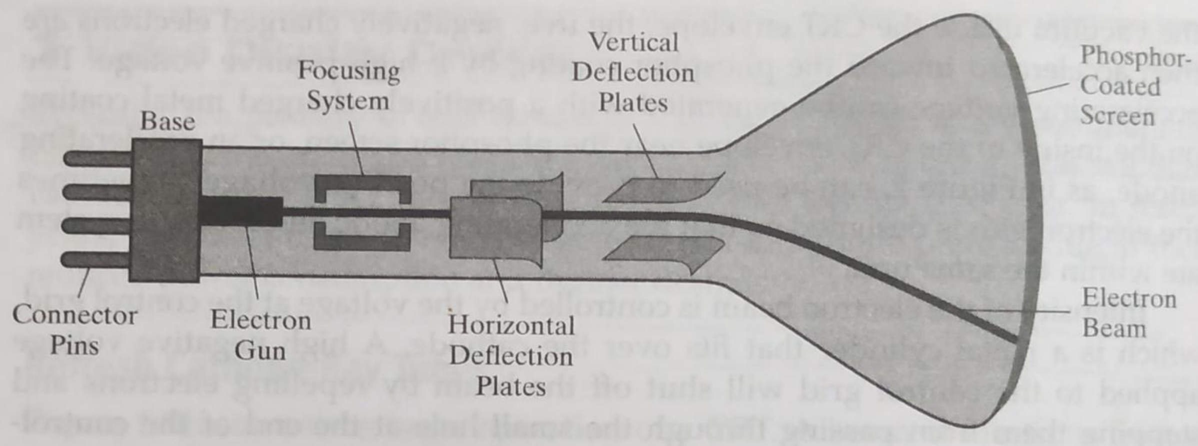
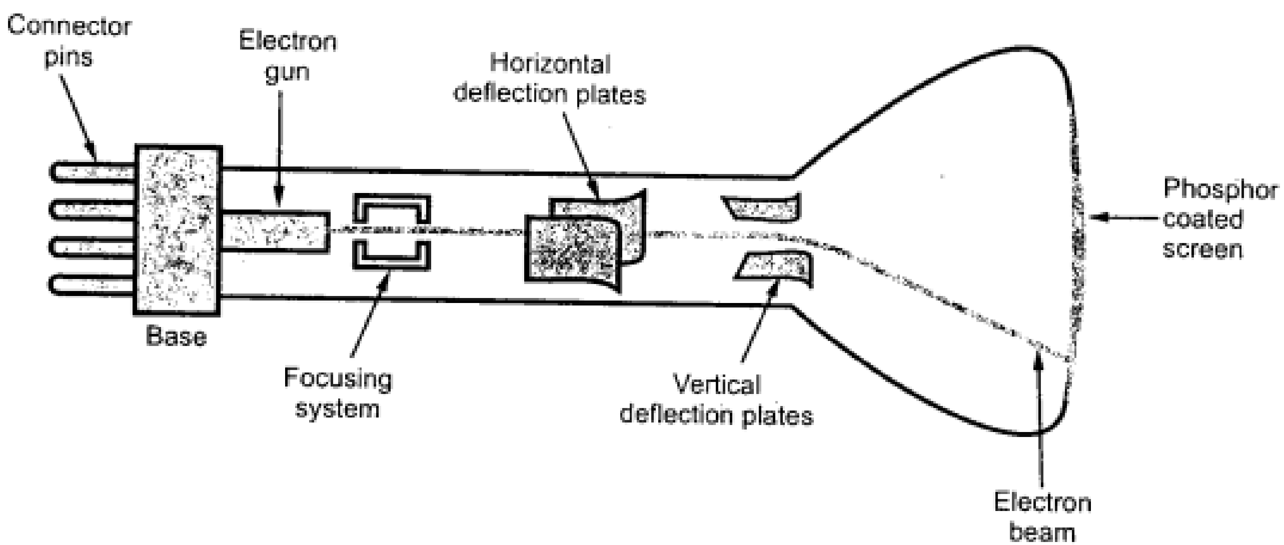
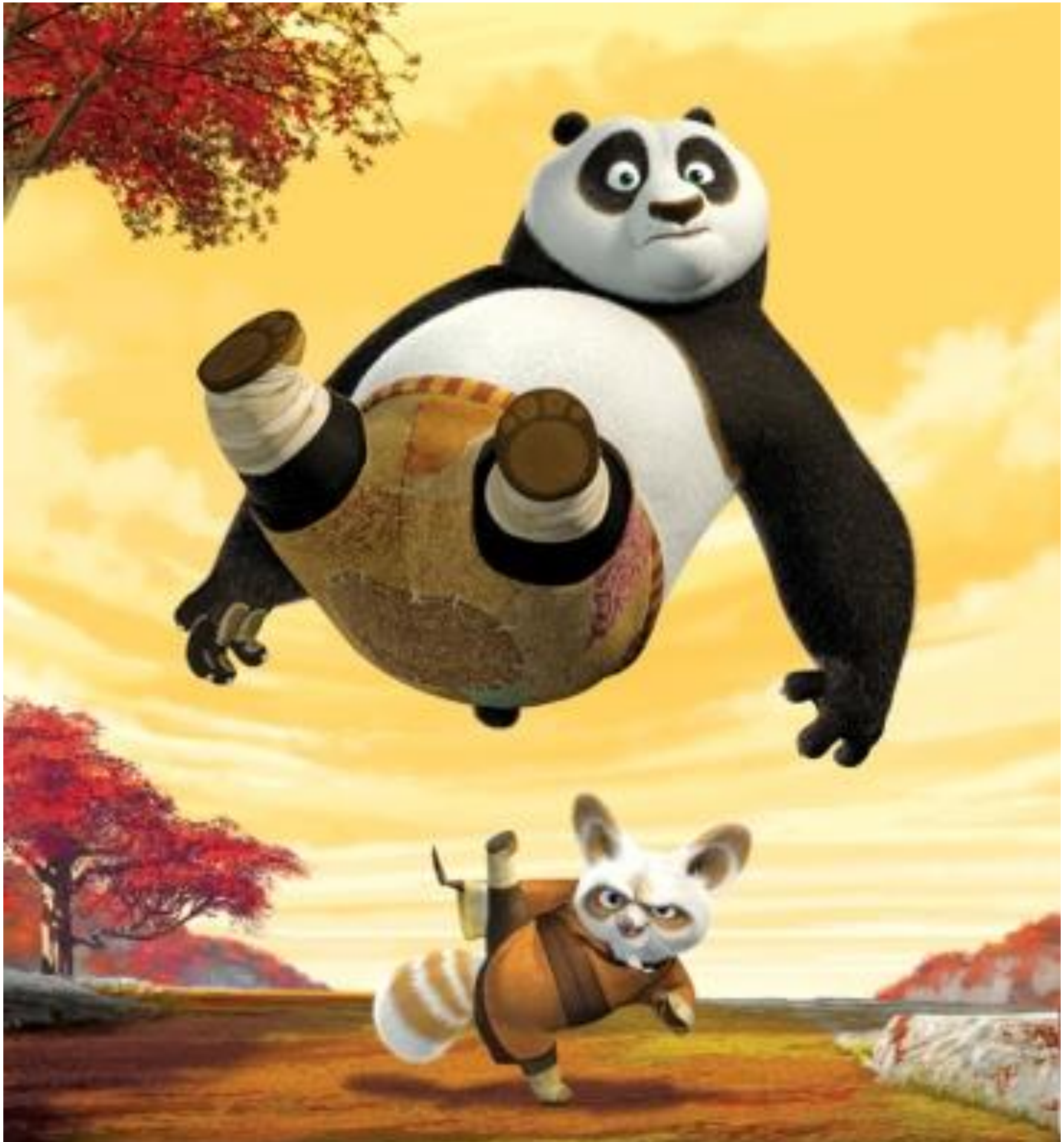


FIGURE 3
Electrostatic deflection of the electron beam in a CRT.



Raster-Scan Displays

- In **raster-scan system**, the electron beam is swept across the screen, one row at a time, from top to bottom.
- **Scan-line:** Each row is referred to as a scan-line.
- **Frame buffer** or refresh buffer: Picture definition is stored in a memory area called the refresh buffer or frame buffer.
- **Frame:** Where the term frame refers to the total screen area. This memory area holds the set of color values for the screen points.
- **Pixel or pel:** Each screen spot that can be illuminated by the electron beam is referred to as a pixel.
- Aspect ratio: the number of pixel columns divided by the number of scan lines that can be displayed by the systems. 4/3



Raster-Scan Displays…

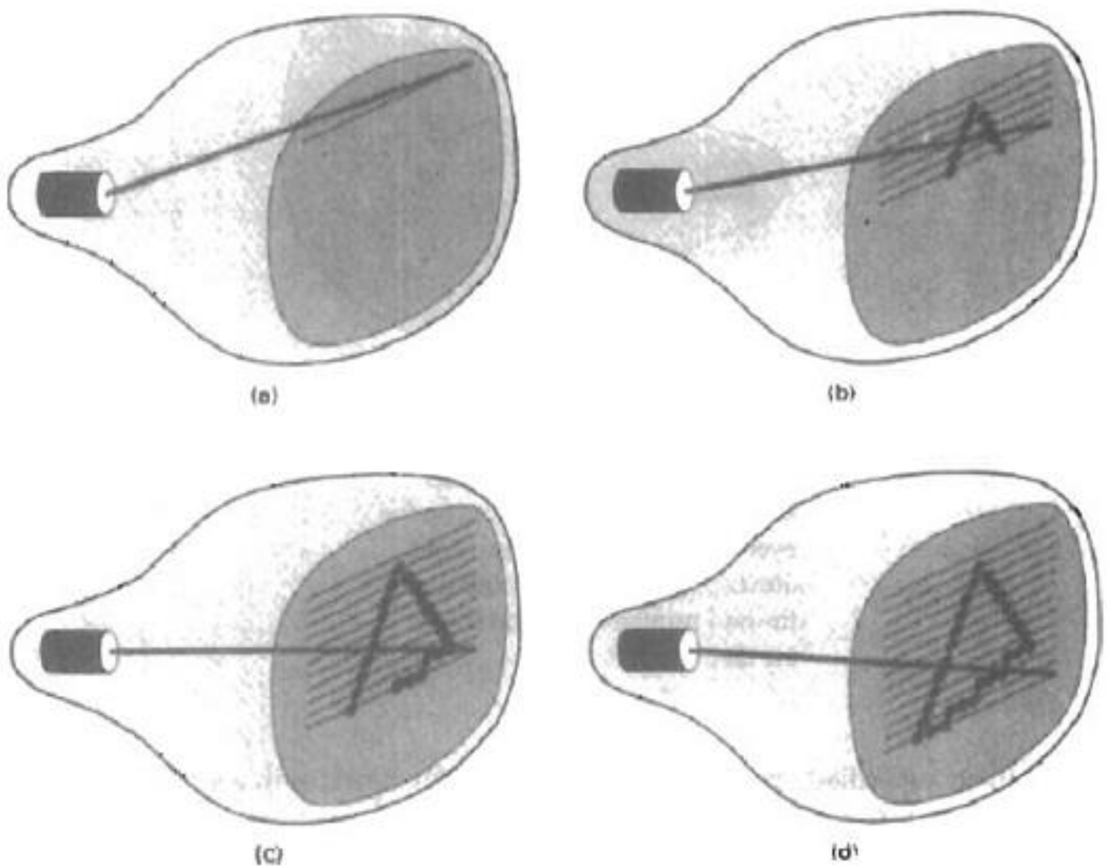


Figure 2-7
A raster-scan system displays an object as a set of discrete points across each scan line.

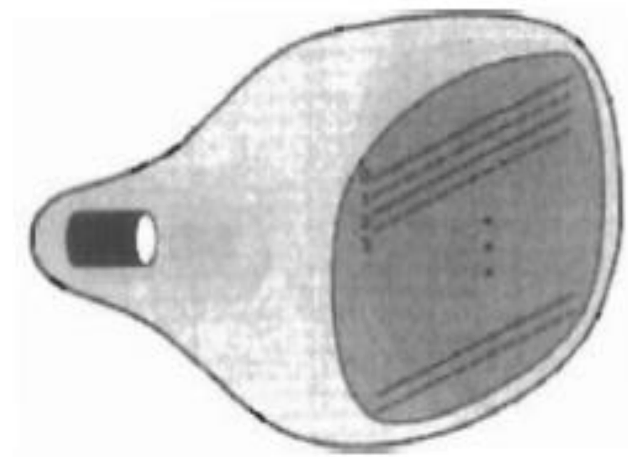
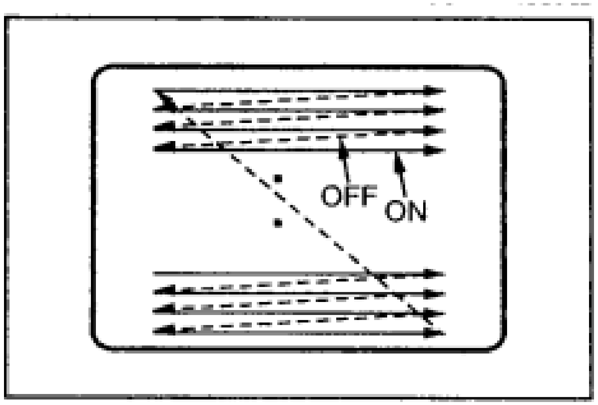
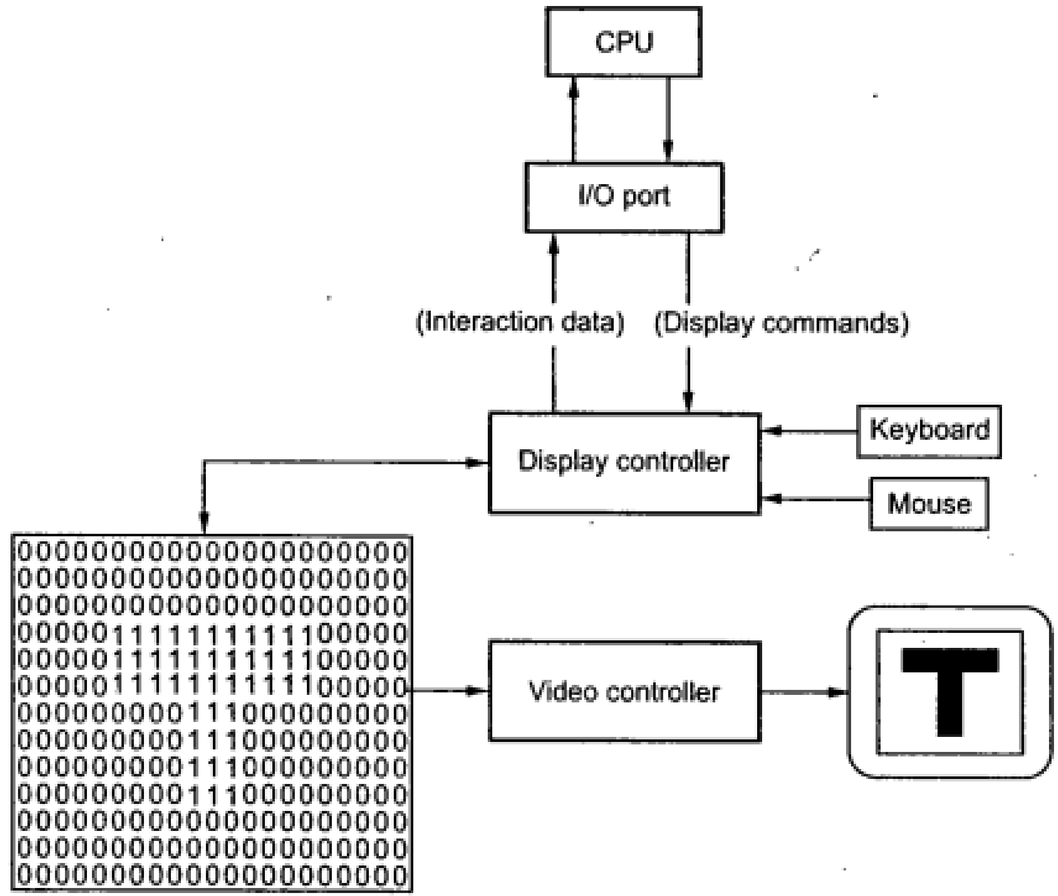


Figure 2-8
Interlacing scan lines on a raster-scan display. First, all points on the even-numbered (solid) scan lines are displayed; then all points along the odd-numbered (dashed) lines are displayed.

Raster Scan Display Architecture





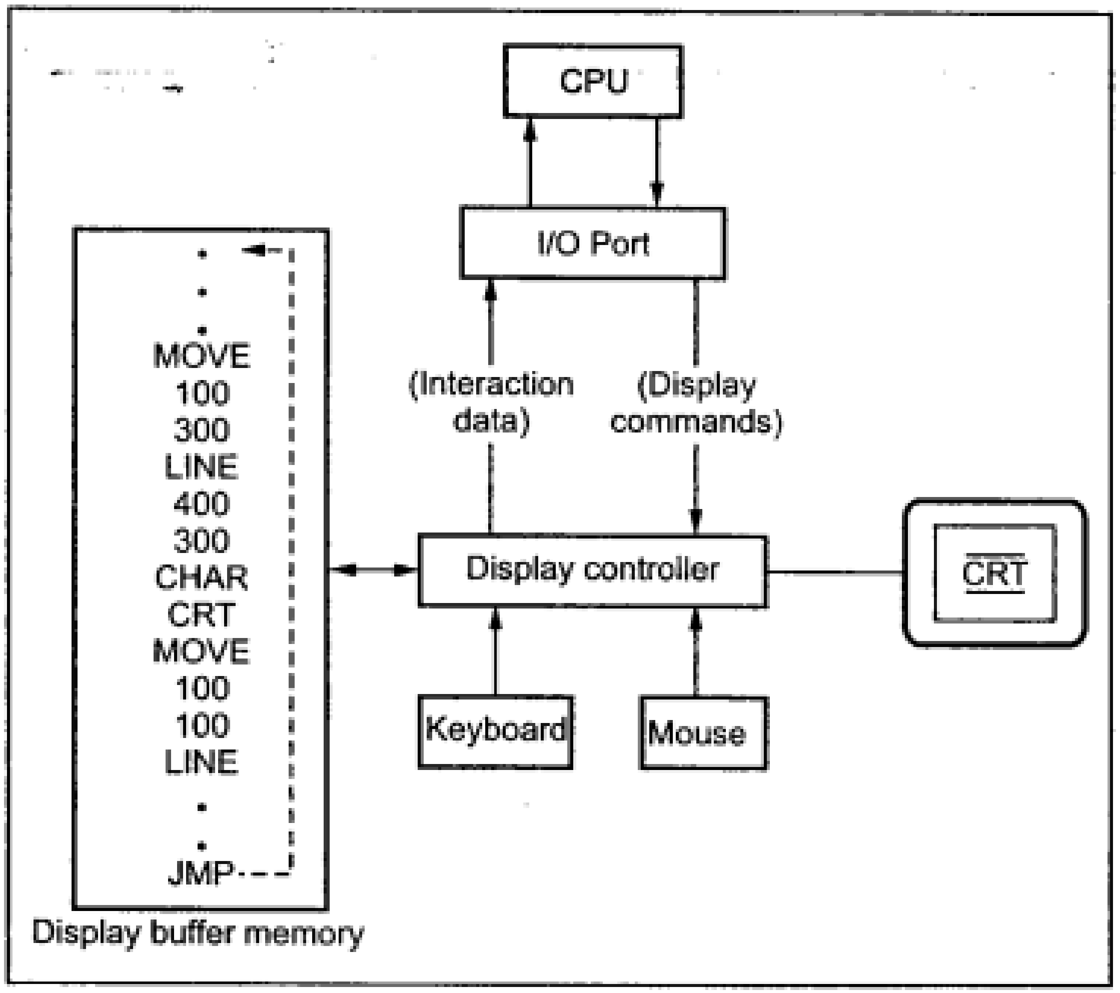
Refresh buffer

Random-Scan Displays

- When operated as a random-scan display unit, a CRT has the electron beam directed only to those parts of the screen where a picture is to be displayed.
- Pictures are generated as line drawings, with the electron beam tracing out the component lines one after the other.
- For this reason, random-scan monitors are also referred to as vector displays or stroke-writing displays or calligraphic displays.

- A pen plotter operates in a similar way and is an example of a random-scan, hard-copy device.
- Refresh rate on a random-scan system depends on the number of lines to be displayed on that system.
- Picture definition is now stored as a set of line-drawing commands in an area of memory referred to as the display list, refresh display file, vector file, or display program.
- Random-scan systems were designed for line-drawing applications, such as architectural and engineering layouts, and they cannot display realistic shaded scenes.

Vector display architecture



Random-Scan Displays…

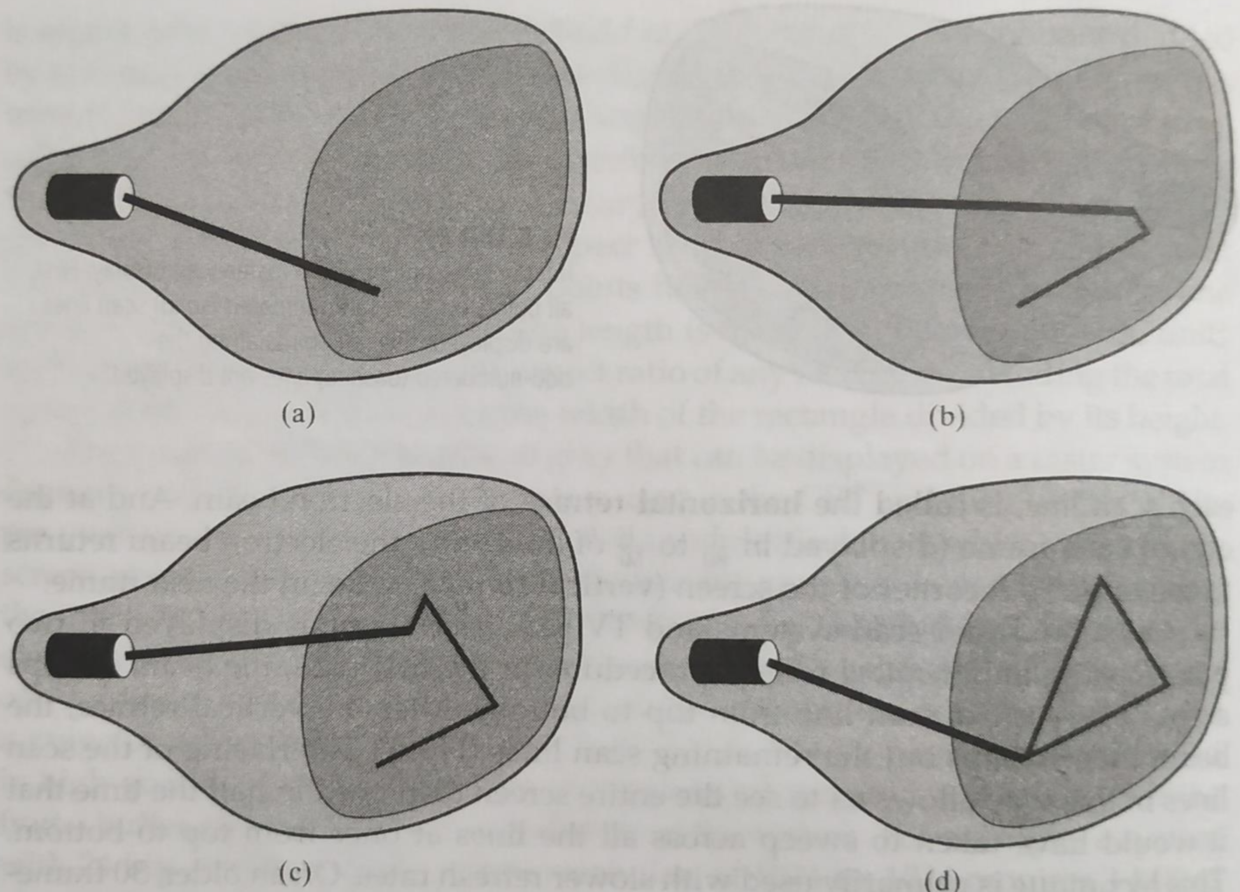
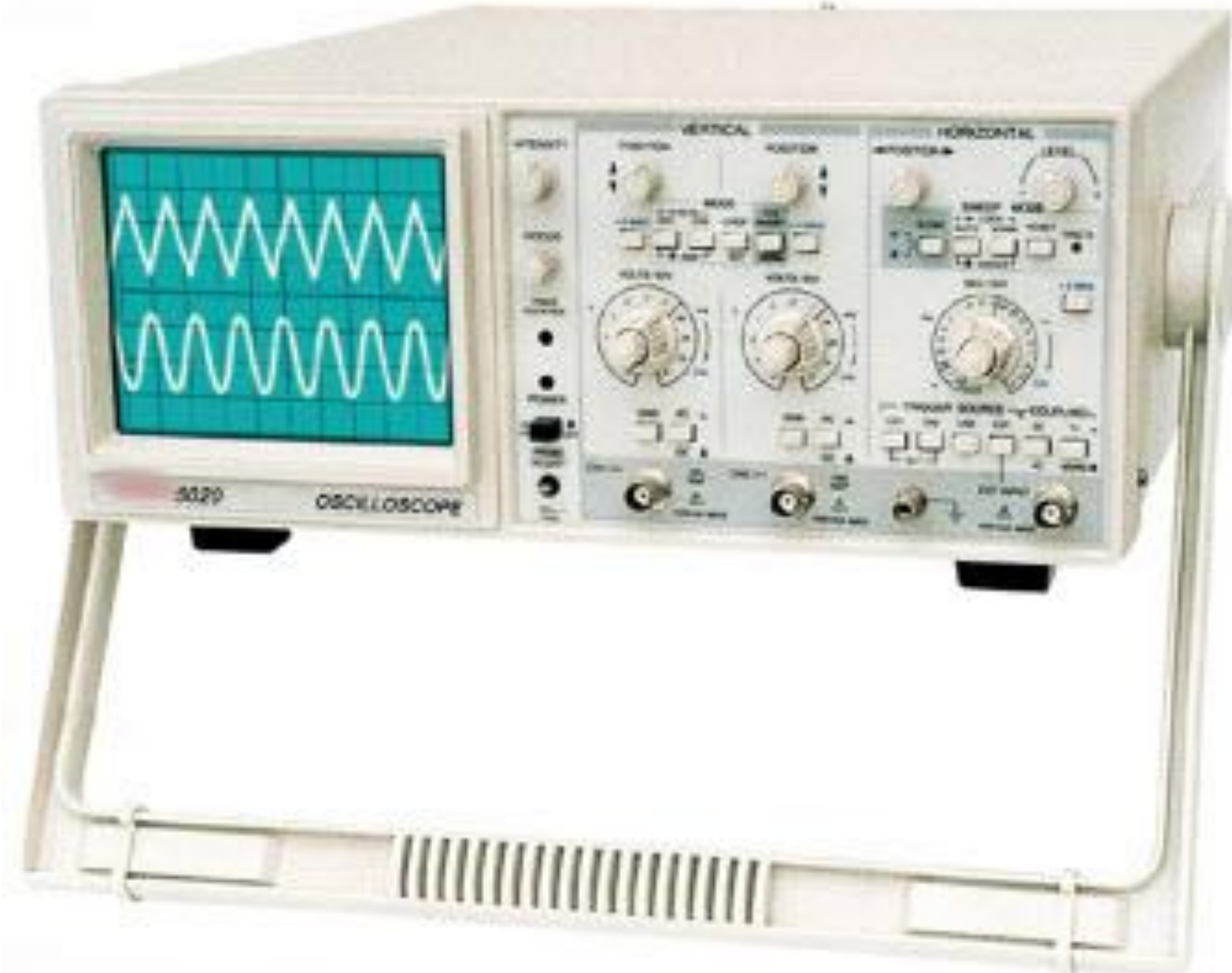


FIGURE 8
A random-scan system draws the component lines of an object in any specified order.


VERTICAL
HORIZONTAL
OSCILLOSCOPE

Color CRT Monitors

- A CRT monitor displays color pictures by using a combination of phosphors that emit different-colored light.

- The emitted light from the different phosphors merges to form a single perceived color, which depends on the particular set of phosphors that have been excited.

Color CRT Monitors…

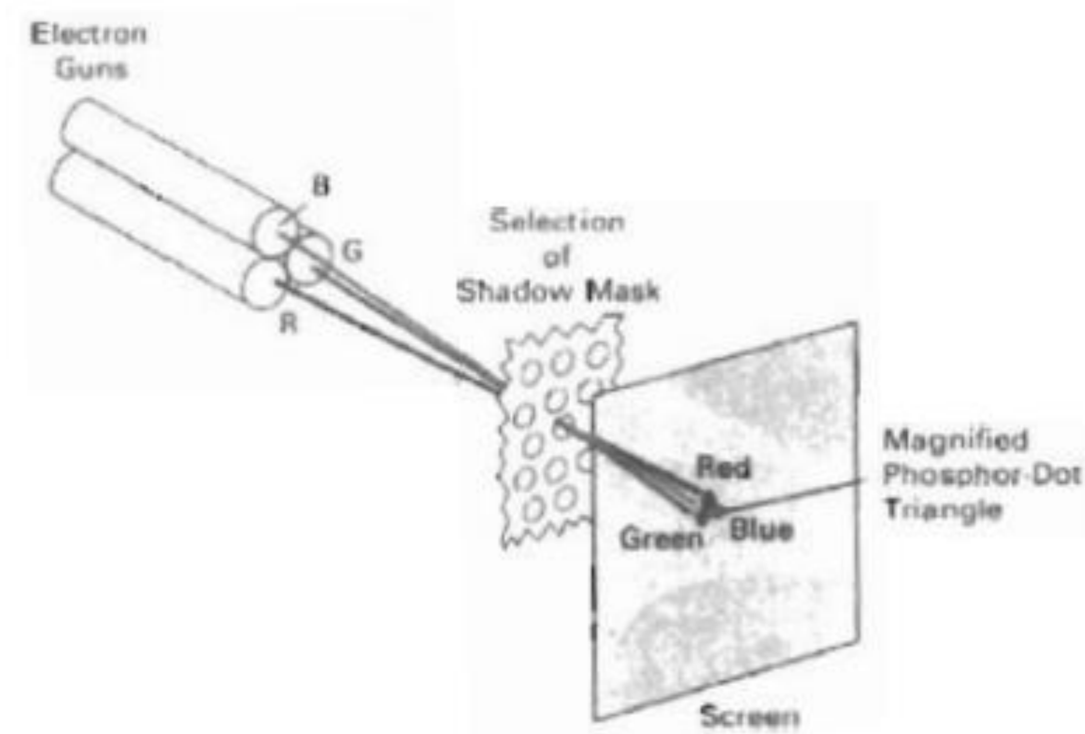
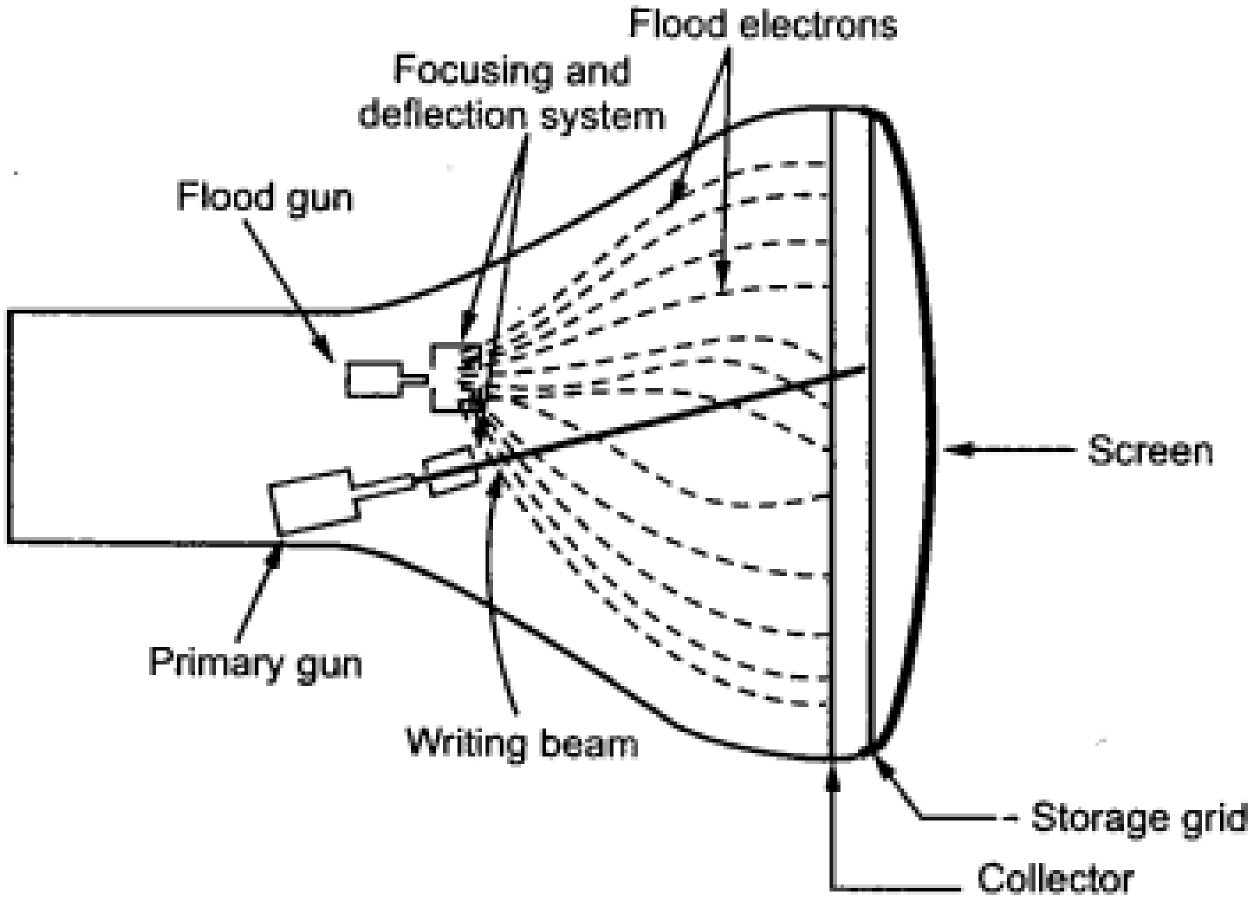


Figure 2-10
Operation of a delta-delta, shadow-mask CRT. Three electron guns, aligned with the triangular color-dot patterns on the screen, are directed to each dot triangle by a shadow mask.

- The CRT Monitor display by using a combination of phosphors. The phosphors are different colors.
- There are two popular approaches for producing color displays with a CRT are:
  - Beam Penetration Method
  - Shadow-Mask Method

Direct-view Storage Tubes (DVST)

- The direct-view storage tubes give the alternative method of maintaining the screen image.
- A DVST uses the storage grid which stores the picture information as a charge distribution just behind the phosphor-coated screen.
- It consists of two electron guns: a primary gun (which stores the picture pattern) and a flood gun (which maintains the picture display).


Flood electrons
Focusing and
deflection system
Flood gun
Screen
Primary gun
Writing beam
Storage grid
Collector

Advantages of DVST

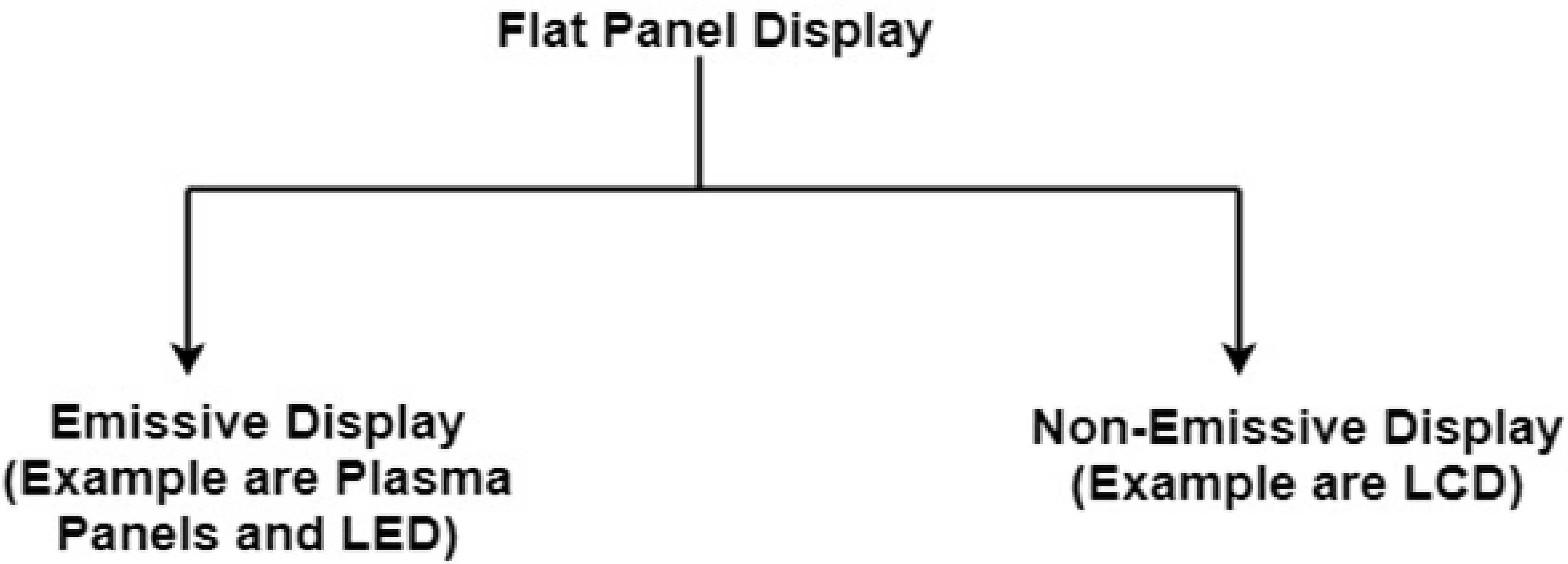
1. Refreshing of CRT is not required.
2. Because no refreshing is required, very complex pictures can be displayed at very high resolution without flicker.
3. It has flat screen.

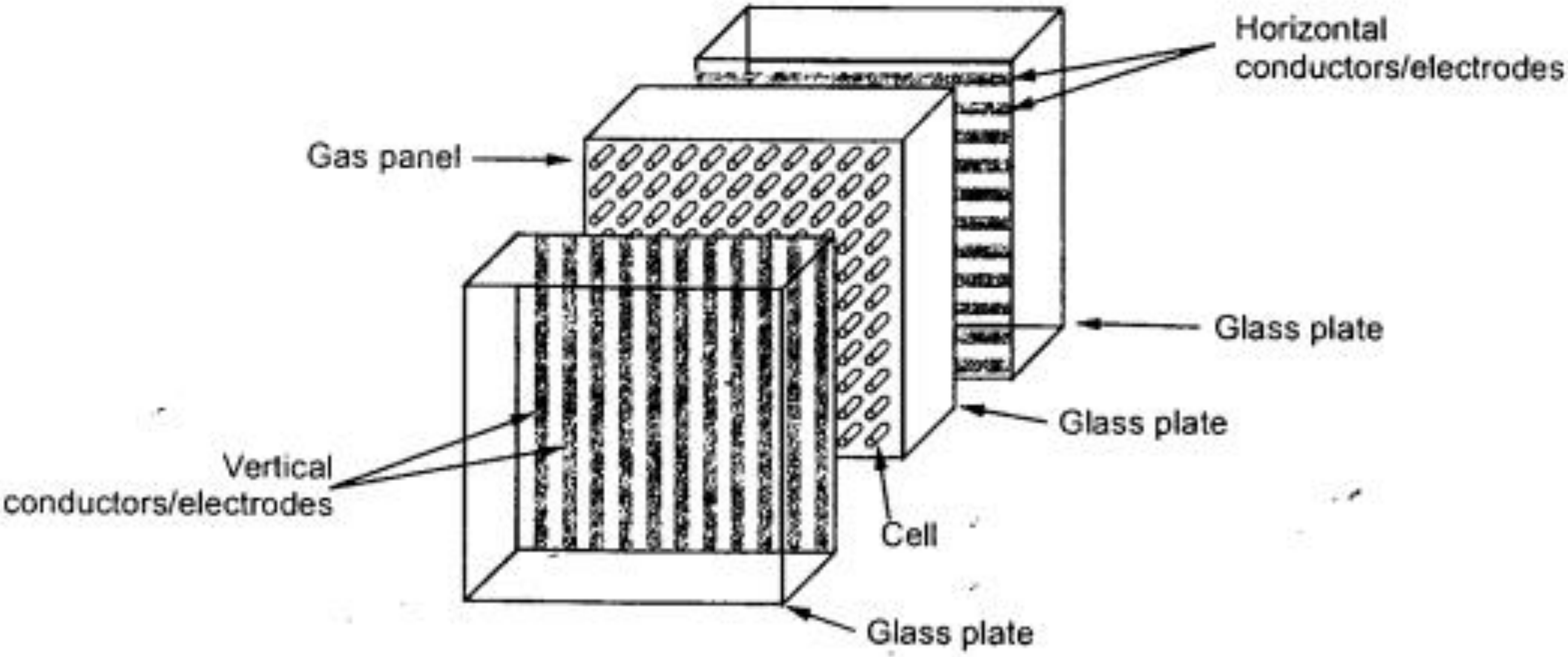
Disadvantages of DVST

1. They do not display colours and are available with single level of line intensity.
2. Erasing requires removal of charge on the storage grid. Thus erasing and redrawing process takes several seconds.
3. Selective or part erasing of screen is not possible.
4. Erasing of screen produces unpleasant flash over the entire screen surface which prevents its use of dynamic graphics applications.
5. It has poor contrast as a result of the comparatively low accelerating potential applied to the flood electrons.
6. The performance of DVST is some what inferior to the refresh CRT.

Flat Panel: Plasma Panel Display

- Also called gas-discharge displays.
- Plasma panel display writes images on the display surface point by point, each point remains bright after is has been intensified.
- It consists of two plates of glass with thin, closely spaced gold electrodes.
- The gold electrodes are attached to the inner faces and covered with a dielectric material.


Flat Panel Display
Emissive Display
(Example are Plasma
Panels and LED)
Non-Emissive Display
(Example are LCD)


Horizontal
conductors/electrodes
Gas panel
Glass plate
Glass plate
Vertical
conductors/electrodes
Cell
Glass plate

Advantages

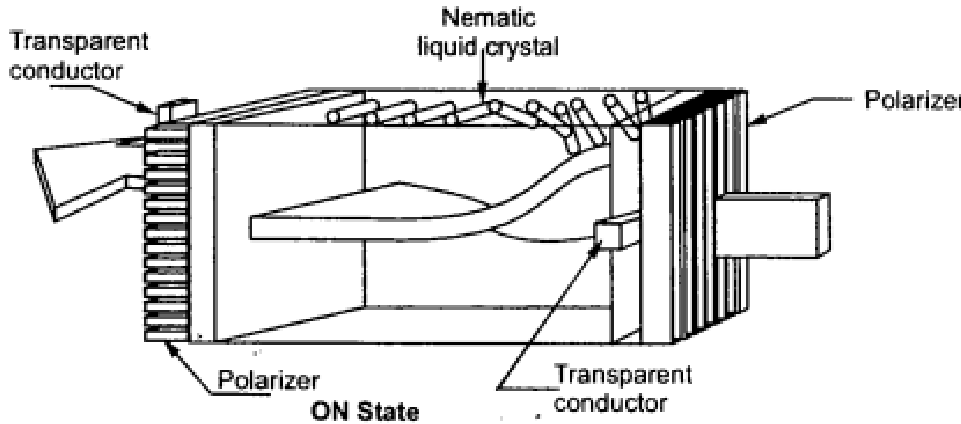
1. Refreshing is not required.
2. Produces a very steady image, totally free of flicker.
3. Less bulky than a CRT.
4. Allows selective writing and selective erasing, at speed of about 20 μsec per cell.
5. It has the flat screen and is transparent, so the displayed image can be superimposed with pictures from slides or other media projected through the rear panel.

Disadvantages

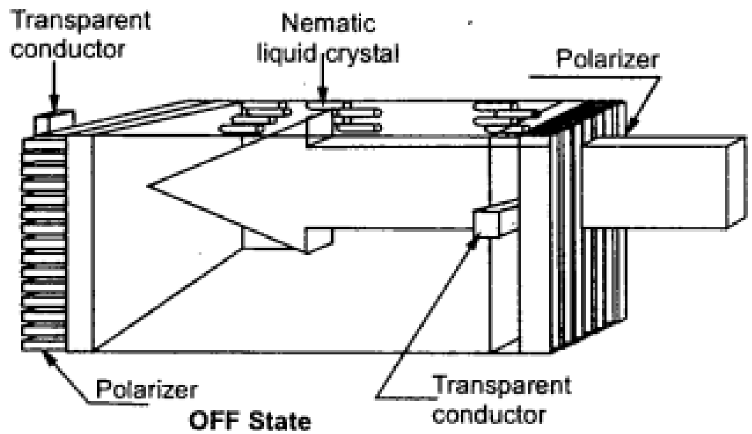
1. Relatively poor resolution of about 60 dots per inch.
2. It requires complex addressing and wiring.
3. Costlier than the CRTs.

Liquid Crystal Monitors

- The term liquid crystal refers to the fact that these compounds have a crystalline arrangement of molecules, yet they flow like a liquid.
- Flat panel displays commonly use nematic (thread like) liquid-crystal compounds that tend to keep the long axes of the rod-shaped molecules aligned.
- Two glass plates, each containing a light polarizer at right angles to the other plate sandwich the liquid-crystal material.
- Rows of horizontal transparent conductors are built into one glass plate, and columns of vertical conductors are put into the other plate.
- The intersection of two conductors defines a pixel position.

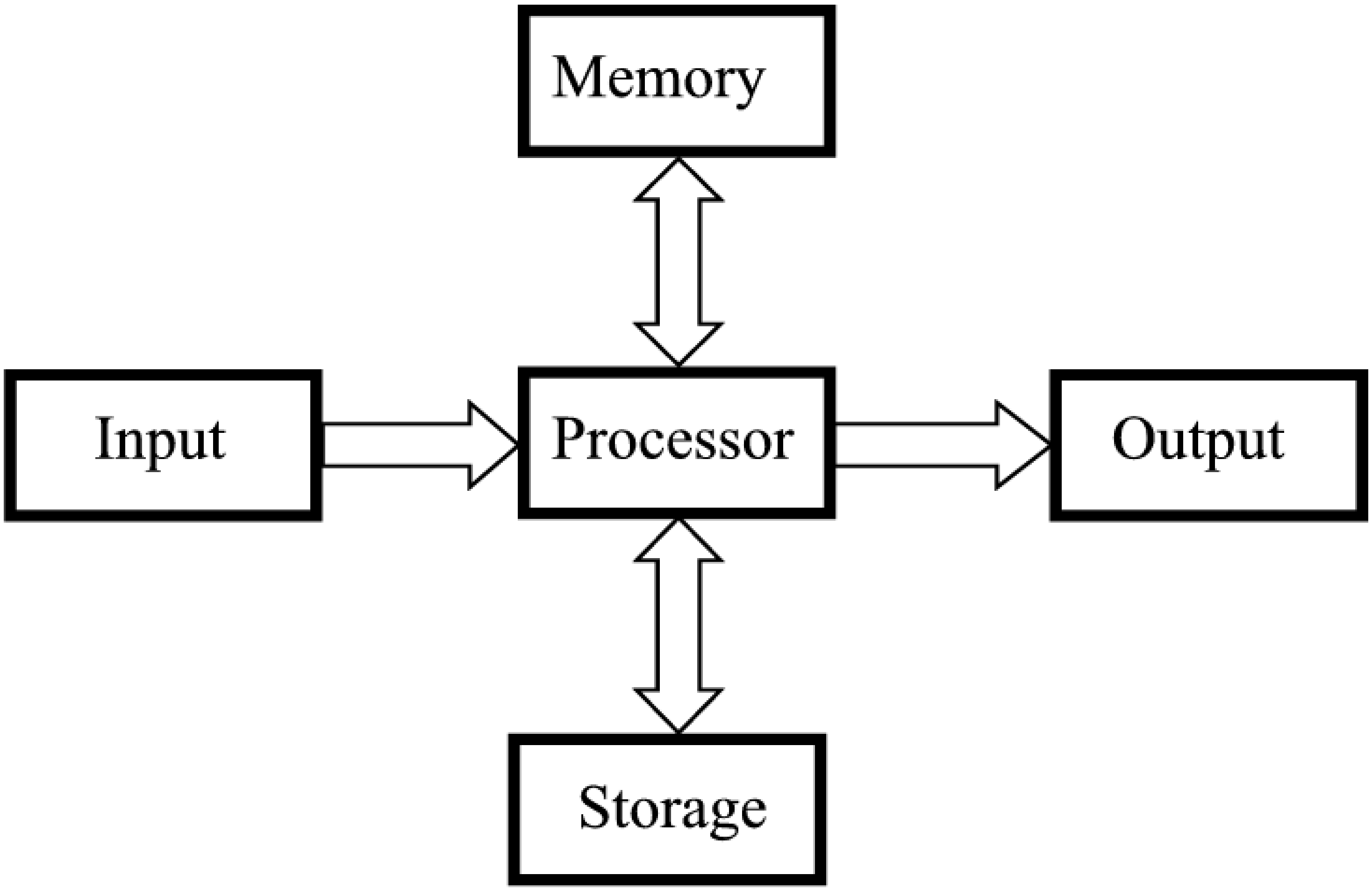


(a) Field effect display 'ON State'



(b) Field effect display 'OFF State'

Graphics Input / Output Devices



Problems

1. A video monitor has a display area measuring 12 inch by 9.6 inch. If the resolution is 1280x1024 and the aspect ratio is 1. What is the diameter of each screen point.
2. What is the fraction of the total refresh time per frame spent in retrace of the electron beam for a non-interlaced raster system with a resolution of 1280x1024, a refresh rate of 60Hz, a horizontal retrace time of 5microsecond and a vertical retrace time of 500 microseconds?

What’s available for input…

- touch - fingers, feet, breath
- sound - voice, other sounds
- gesture
- gaze
- brainwaves…

Input Devices

•Used by a person to communicate to a computer.

Person to computer

and output…

- textual information
- visual images - photos, diagrams, icons
- moving images
- sounds - music, voice
- Etc..

Output Devices

•Displays information from the computer to a person.

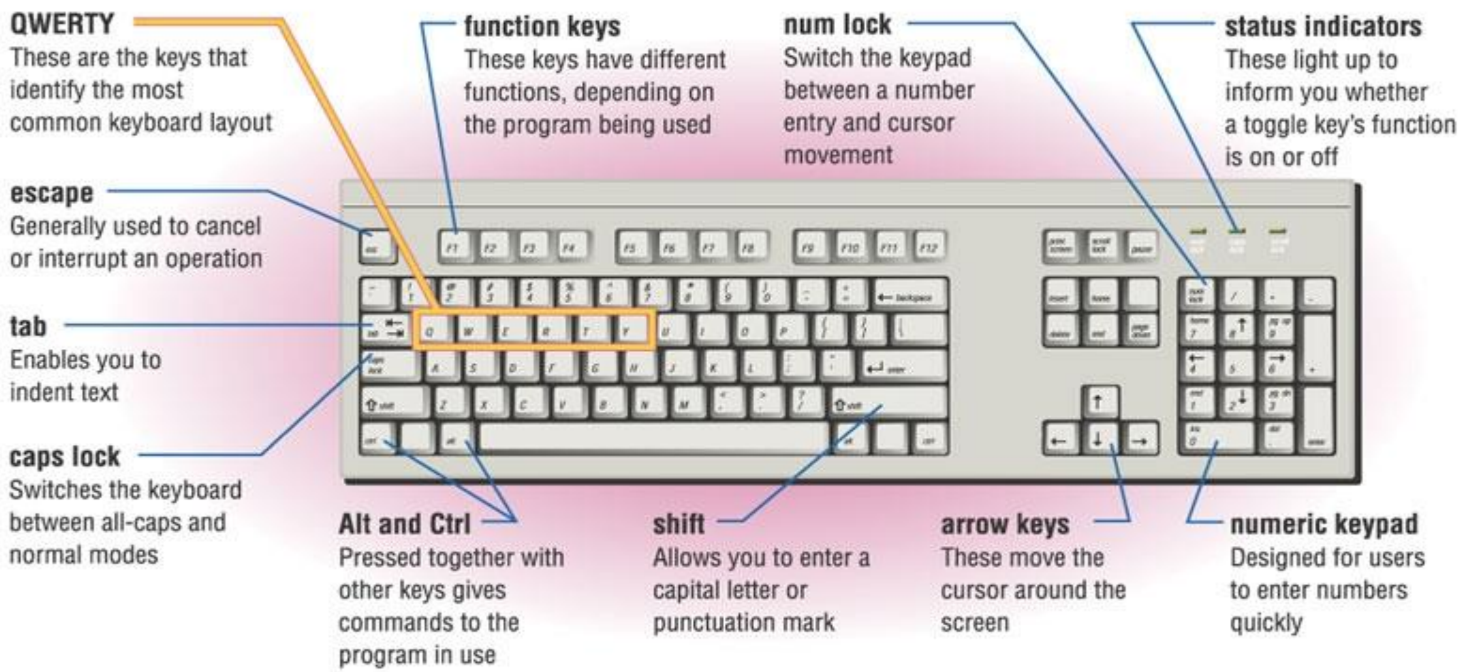
Input Devices

- Keyboard.
- Mouse
- Microphone
- Digital Camera
- Scanner

The Keyboard

The most commonly used input device is the keyboard on which data is entered by manually keying in or typing certain keys. A keyboard typically has 101 or 105 keys.

Keyboard



- The keyboard allows the computer user to enter words, numbers, punctuation, symbols, and special function commands into the computer's memory.

The Mouse

Is a pointing device which is used to control the movement of a mouse pointer on the screen to make selections from the screen. A mouse has one to five buttons. The bottom of the mouse is flat and contains a mechanism that detects movement of the mouse.

Pointing devices - direct

- **Touch screens**

Touch screens

- Often used for applications with occasional use, for example
- Bank ATMs, Information Kiosks, etc.
- No extra hardware - used for input and for output
- Can be precise to 1 pixel
- Good for menu choice - not so good for other functions
- Intuitive to use

Touch screens

- BUT

- Tiring if at wrong angle (needs to be 30-45% from horizontal)
- Get greasy, jammy
- Finger can obscure screen
- Alternative - use stylus to touch screen, or lightpen

Indirect Pointing Devices

- Need more cognitive processing than direct methods, but can be more efficient

- mouse
- tracker ball
- track point
- touchpad…

Indirect pointing devices - other

- Tracker ball, trackpad, trackpoint
- Less space on desktop
- Good in moving environments, e.g. car, train

Indirect pointing devices - other

- Joystick
- The main use of a joystick is to play computer games by controlling the way that something moves on the screen.

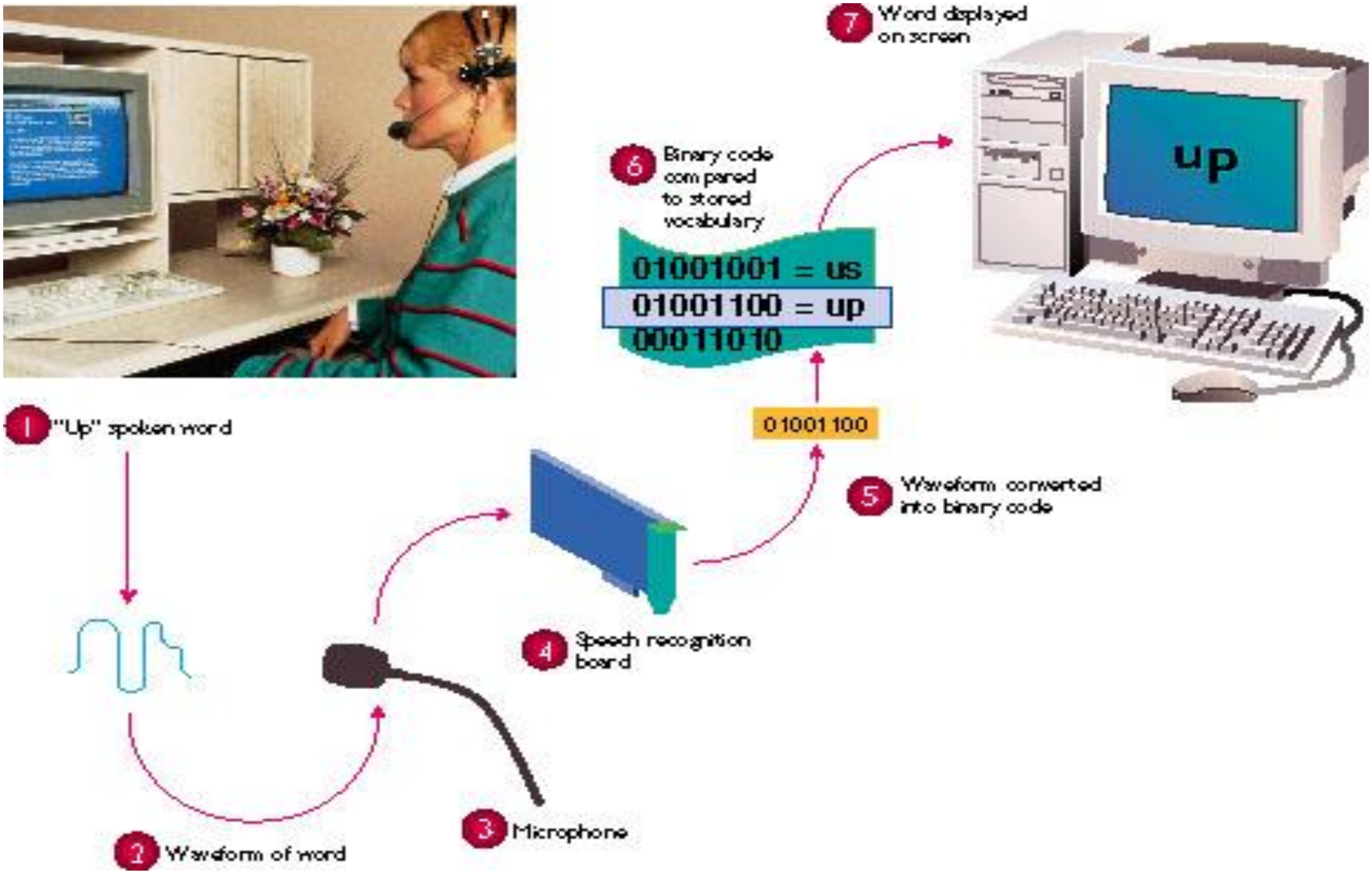
Microphones - Speech Recognition

- Use a microphone to talk to your computer
  - Add a sound card to your computer
  - Sound card digitizes audio input into 0/1s
- A speech recognition program can process the input and convert it into machine-recognized commands or input

Audio Input: Speech Recognition

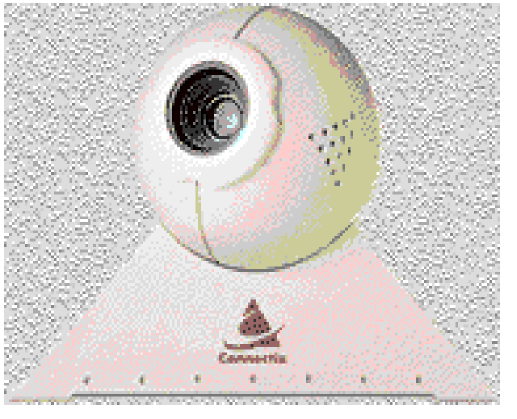
- **Speech recognition** is a type of input in which the computer recognizes words spoken into a microphone.
- Special software and a microphone are required.
- Latest technology uses continuous speech recognition where the user does not have to pause between words.

Microphones - Speech Recognition



Digital camera

A digital camera can store many more pictures than an ordinary camera. Pictures taken using a digital camera are stored inside its memory and can be transferred to a computer by connecting the camera to it. A digital camera takes pictures by converting the light passing through the lens at the front into a digital image.



Scanner

A scanner can be used to input pictures and text into a computer. There are two main types of scanner; Hand-held and Flat-bed.

Light pen

- A light pen is a small ‘pen-shaped’ wand, which contains light sensors.
- It is used to choose objects or commands on the screen either by pressing it against the surface of the screen or by pressing a small switch on its side.
- A signal is sent to the computer, which then works out the light pen’s exact location on the screen.
- The advantage of a light pen is that it doesn’t need a special screen or screen coating.

Bar codes

- A bar code is a set of lines of different thicknesses that represent a number

- Bar Code Readers are used to input data from bar codes. Most products in shops have bar codes on them

- Bar code readers work by shining a beam of light on the lines that make up the bar code and detecting the amount of light that is reflected back

Output Types

- Text output
- Graphics output
- Video output
- Audio output

Output Devices: Engaging our Senses

- Output devices are peripheral devices that enable us to view or hear the computer’s processed data.
  - **Visual output** – Text, graphics, and video
  - **Audio output** – Sounds, music, and synthesized speech

Output Devices

- Monitors
- Printers
- Speakers
- Data Projectors

Monitors

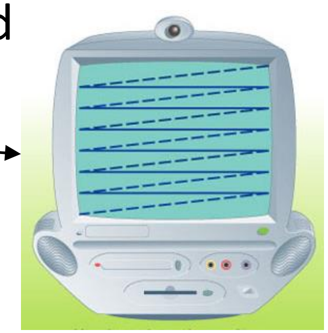
CRT

LCD

- A monitor is a peripheral device which displays computer output on a screen.
- Screen output is referred to as **soft copy**.
- Types of monitors:
  - Cathode-ray tube (CRT)
  - Liquid Crystal Display (LCD or flat-panel)

Monitors

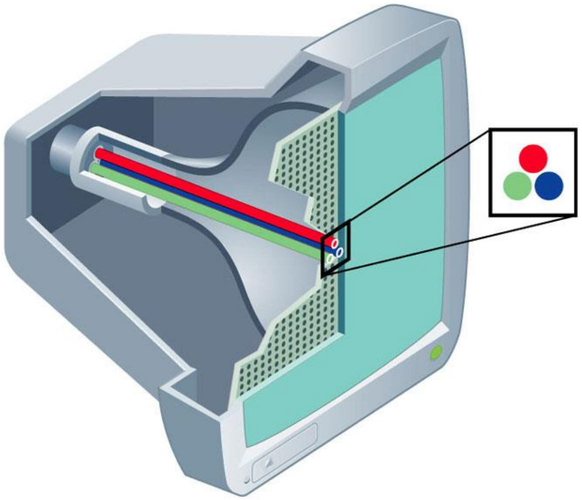
- CRT
  - cathode ray tube
    - electron gun shoots a stream of electrons at a specially phosphor-coated screen
    - on impact, the phosphor flares up for a fraction of a second
    - electron gun sweeps across the screen many times a second



- LCD
  - liquid crystal display
    - one of several types of “flat-panel” displays
    - forms output by solidifying crystals and “backlighting” the image with a light source
  - TV sets are CRTs and many desktop monitors use this technology
  - LCD is primarily used for laptops and other portable devices

Video Display Terminology

- Pixel
  - picture element (smallest unit of an image, basically a single dot on the screen)
- Resolution
  - number of pixels in the image
  - Common resolution size is 1024x768
  - Refresh rate
    - how often a CRT's electron gun rescans
    - LCD displays do not use an electron gun, so do not perform refreshing



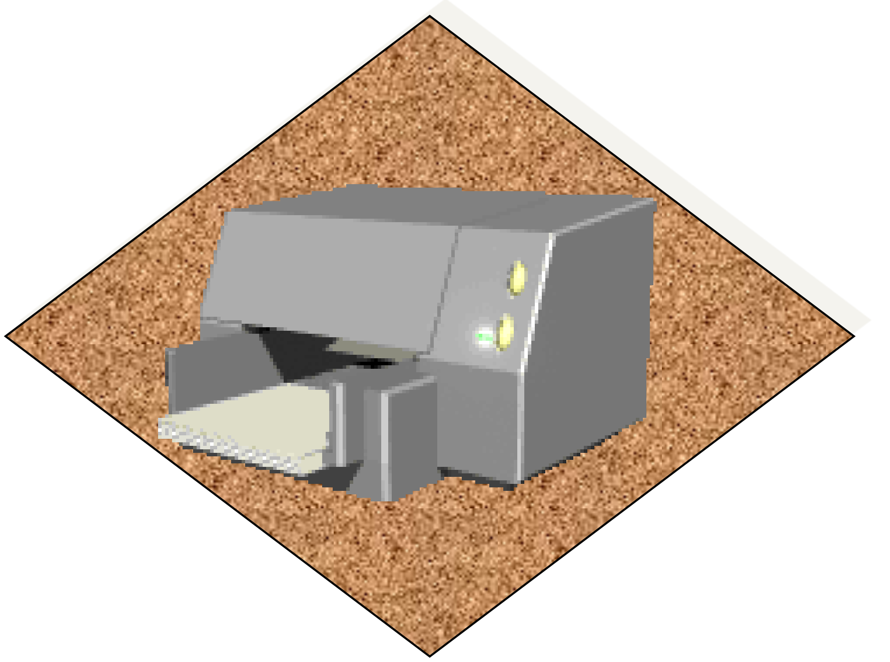
The CRT electron gun "shoots" 3 electrons at the screen representing the amount of red, green and blue for the *pixel*

Printers

- Ink Jet Printer
  - least expensive, color, slower with a higher per page cost than laser printers
- Laser Printer
  - More expensive, faster, lower per page cost than ink jet,

Printers

- A printer is a peripheral device that produces a physical copy or **hard copy** of the computer's output.



Types of Printers

Inkjet

Laser

- **Inkjet printer**, also called a bubble-jet, makes characters by inserting dots of ink onto paper
- Letter-quality printouts
- Cost of printer is inexpensive but ink is costly

- **Laser printer** works like a copier
- Quality determined by dots per inch (dpi) produced
- Color printers available
- Expensive initial costs but cheaper to operate per page

Plotter

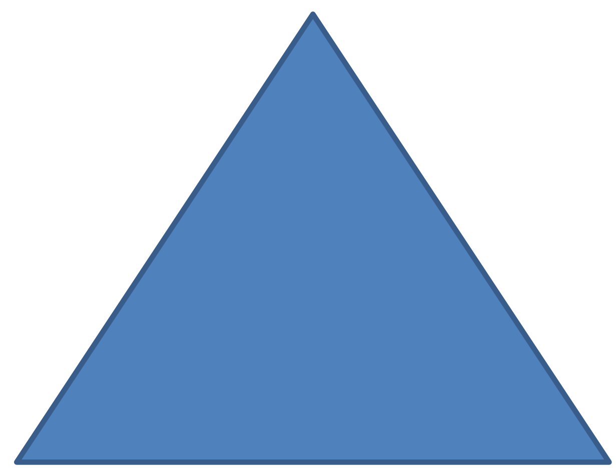
- A plotter is a printer that uses a pen that moves over a large revolving sheet of paper.
- It is used in engineering, drafting, map making, and seismology.

Audio Output: Sound Cards and Speakers

- Audio output is the ability of the computer to output sound.
- Two components are needed:
  - **Sound card** – Plays contents of digitized recordings
  - **Speakers** – Attach to sound card

Virtual Reality I/O Devices

- VR Triangle or I3



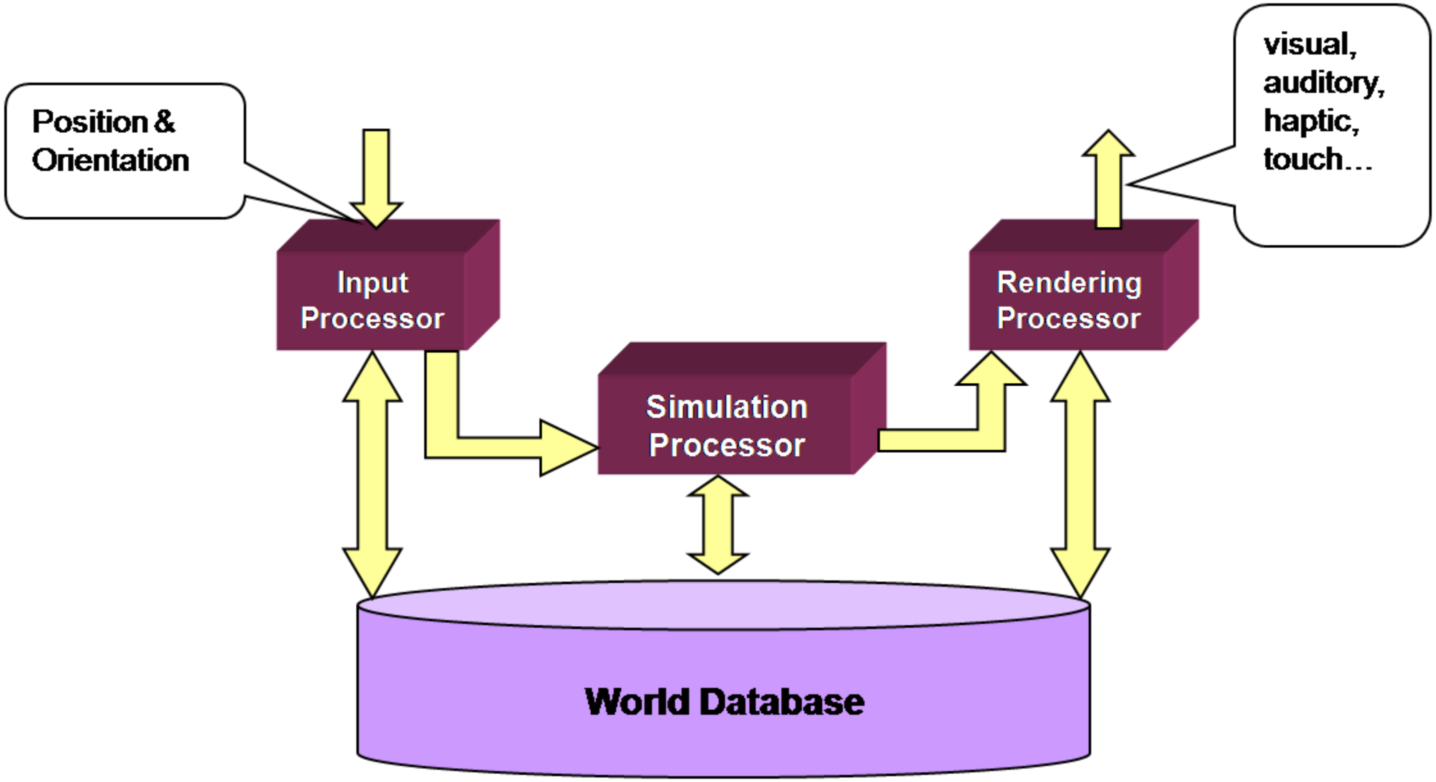
What is Virtual Reality?

Definition:

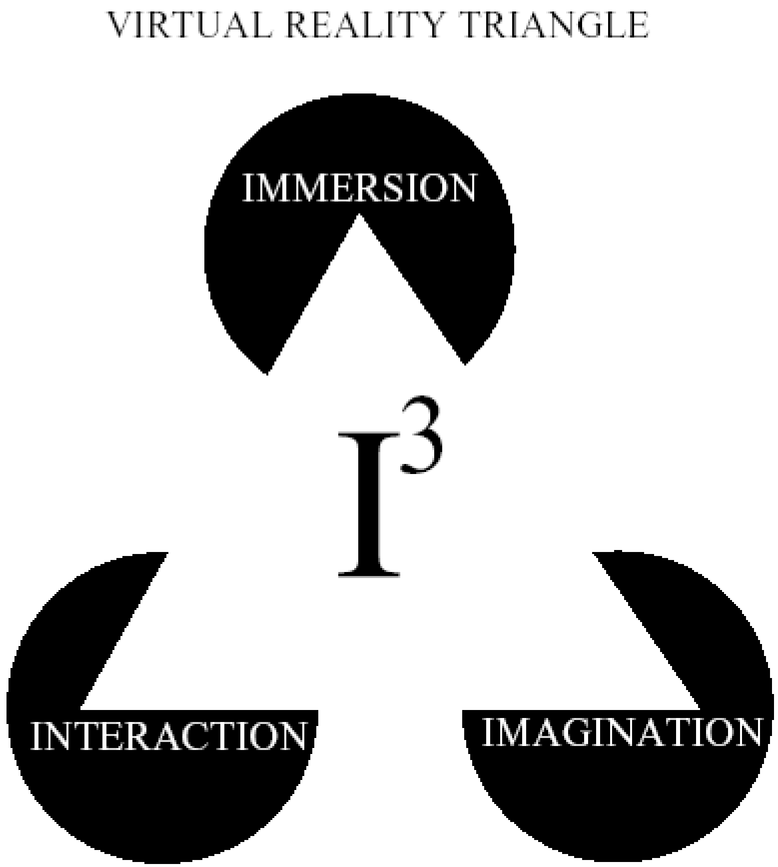
Virtual Reality is a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell and taste.

“It is a computer-simulated reality which replicates an environment, real or imagined and simulates a user’s physical presence and environment to allow for user interaction”

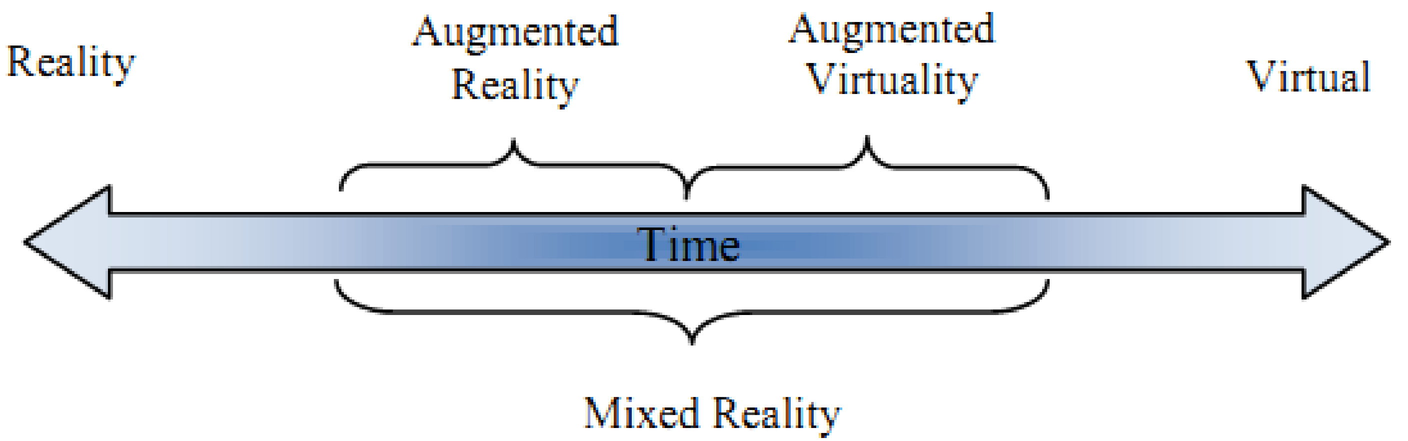
VR System Architecture…



Virtual Reality Triangle



Mixed Reality Timeline



Augmented Reality

- It is a virtuality environment, means virtual content in real environment.

- AR is a live direct or indirect view of a physical, real-world environment whose elements are augmented or supplemented by computer-generated sensory input such as sound, video, graphics or GPS data.

Techniques of Virtual/Mixed Reality

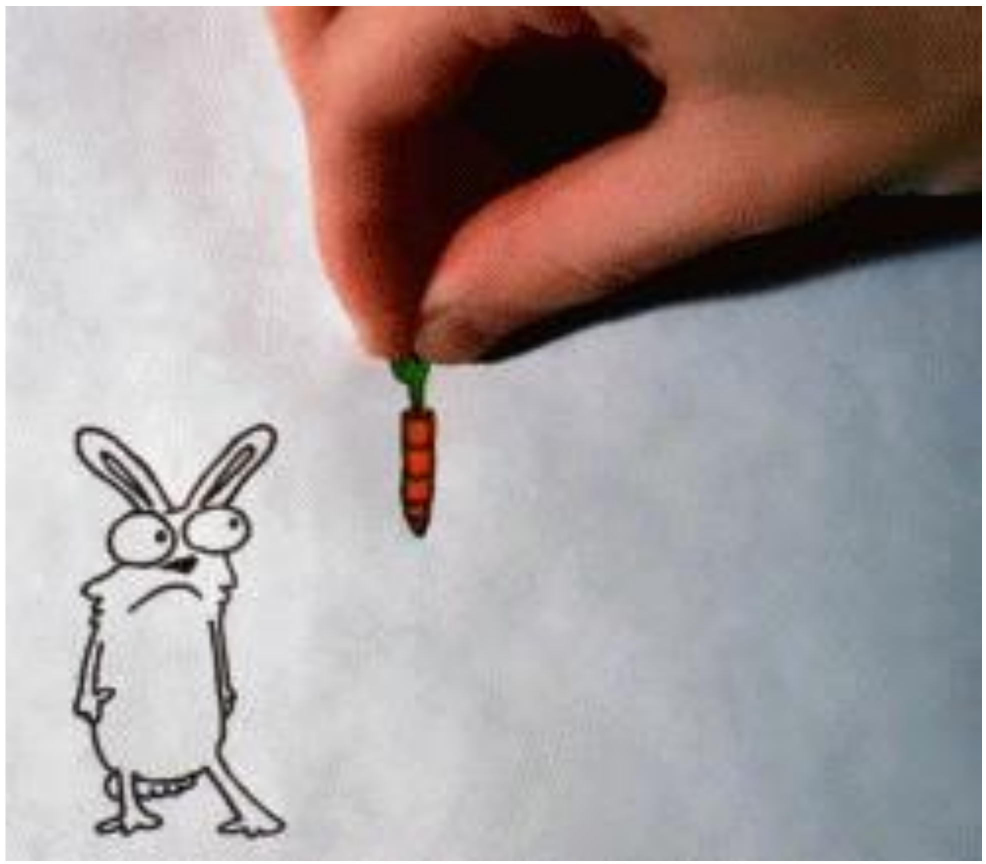
- Modeling
  - Geometric modeling
  - Kinematics modeling
  - Physical modeling
  - Behavior modeling
  - Model management

Continue…

- Selection and Manipulation
- Travel
- Wayfinding

- Hand Dataglove...
- Head Mounted Display
- Eye Tracker

Virtual Reality Equipments

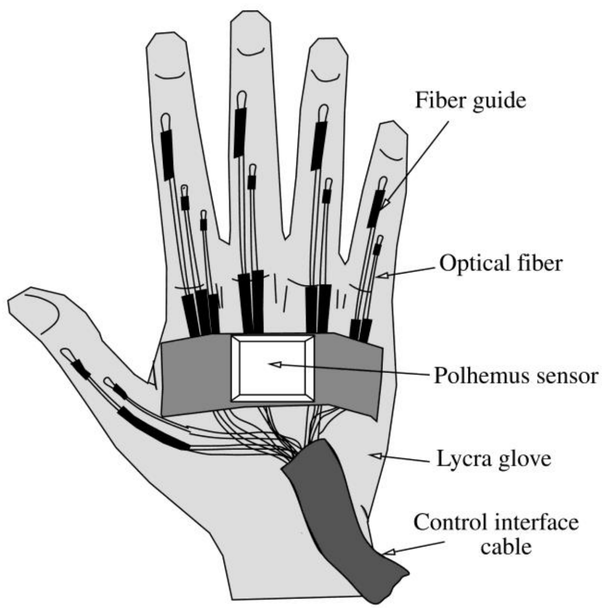


Hand Dataglove

Figure 2-45
A virtual-reality scene, displayed on a two-dimensional video monitor, with input from a data glove and a spaceball. (*Courtesy of The Computer Graphics Center, Darmstadt, Germany.*)

Continue…

- Hand Dataglove



Continue…

- Head Mounted Display (HMD)

Head Mounted Display

Continue…

- Full body motion tracker

Eye Tracker

3D Space controller

Continue…

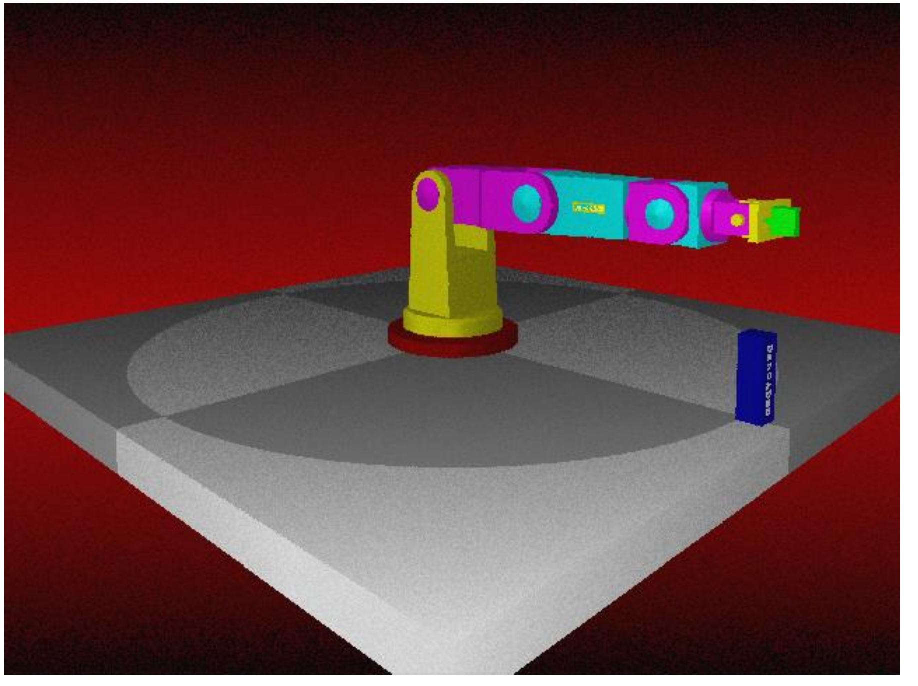
- CAVE (Cave Automatic Virtual Environment)

Continue…

- Face tracker

Virtual Reality tools and packages

- Cortona 3D
- VRML
- OpenSceneGraph
- WorldToolKit
- Java 3D
- APIs
- AR toolkits



Demo Videos

- Traditional application
  - Medical applications 1 2
  - Education, Arts, and Entertainment 1
  - Military VR applications 1

Continue…

- Emerging applications of VIR
  - VR applications in manufacturing
  - Applications of VR in Robotics 1 2
  - Information Visualization 1 2

3. Raster-Scan Systems

- Interactive raster-graphics systems typically employ several processing units.
- In addition to the CPU, a special-purpose processor, called the video controller or display controller, is used to control the operation of the display device.
- Here, the frame buffer can be anywhere in the system memory, and video controller accesses the frame buffer to refresh the screen.

Click to add text
Click to add text

Video Controller

- A fixed area of the system memory is reserved for the frame buffer, and the video controller is given direct access to the frame-buffer memory.
- Frame-buffer locations, and the corresponding screen positions, are referenced in Cartesian coordinates.

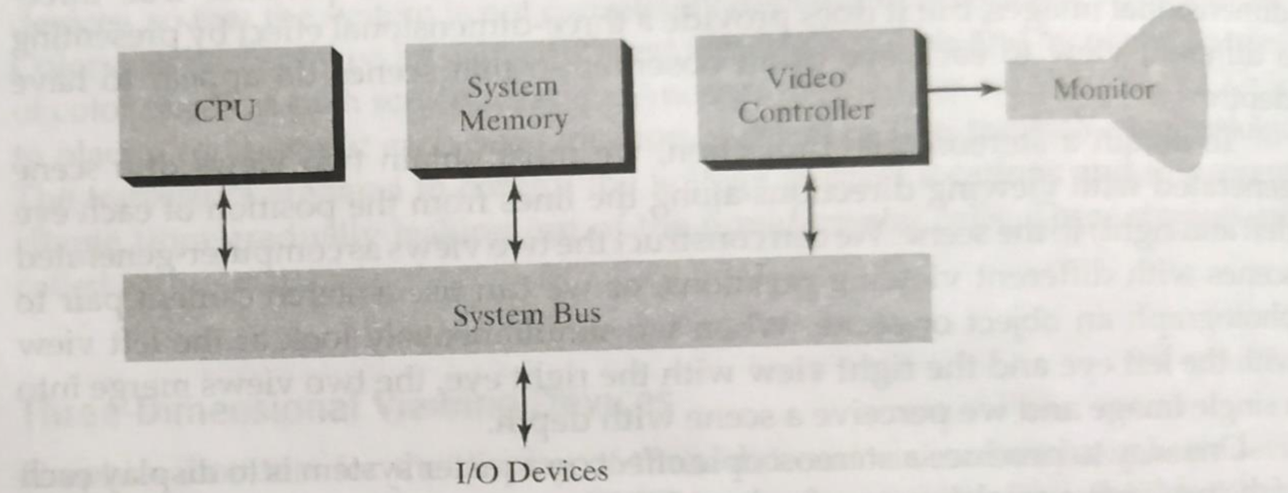


FIGURE 16
Architecture of a simple raster-graphics system.

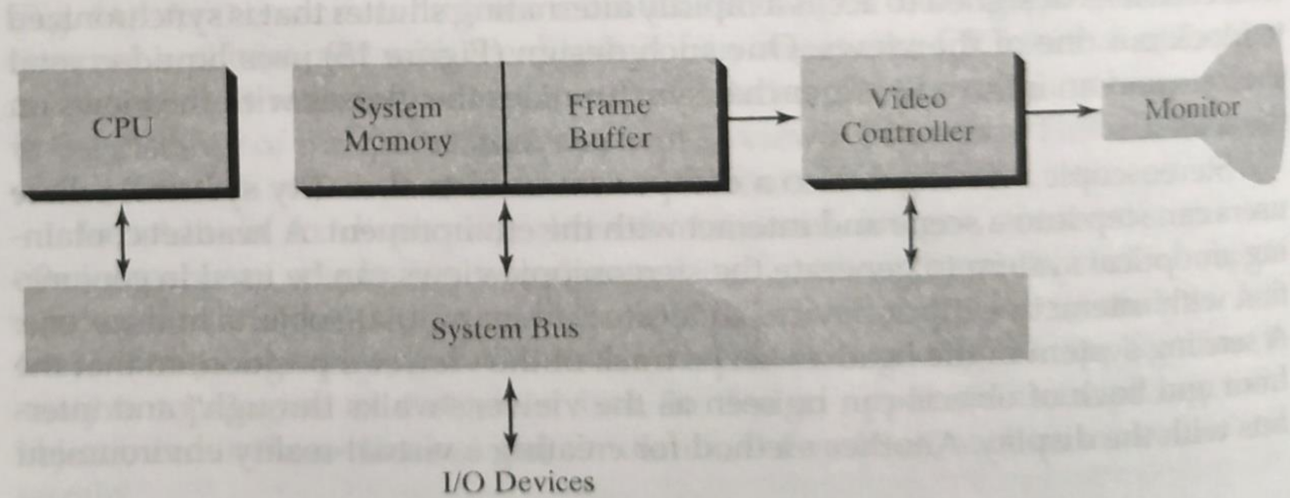


FIGURE 17
Architecture of a raster system with a fixed portion of the system memory reserved for the frame buffer.

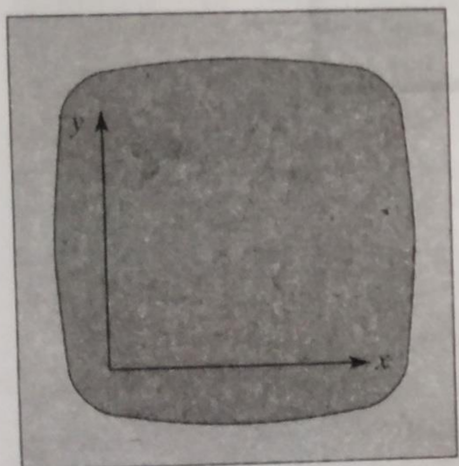


FIGURE 18
A Cartesian reference frame with origin at the lower-left corner of a video monitor.

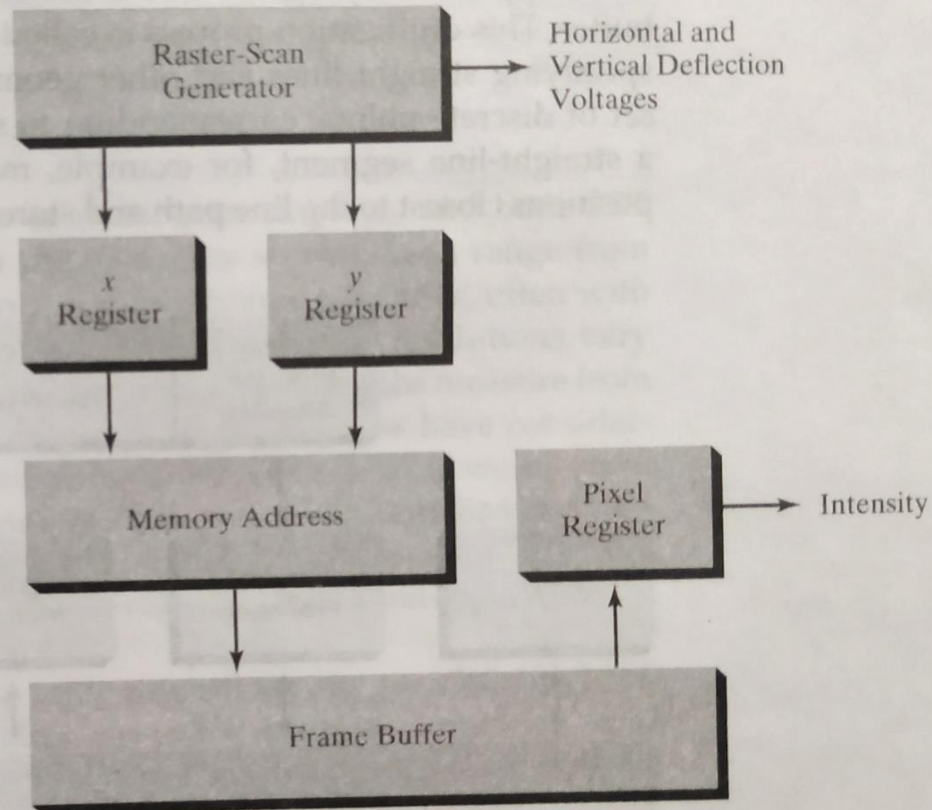


FIGURE 19
Basic video-controller refresh operations.

Raster-Scan Display Processor

- A major task of the display processor is digitizing a picture definition given in an application program into a set of pixel values for storage in the frame buffer.
- This digitization process is called **scan conversion** also known as **rasterization**.

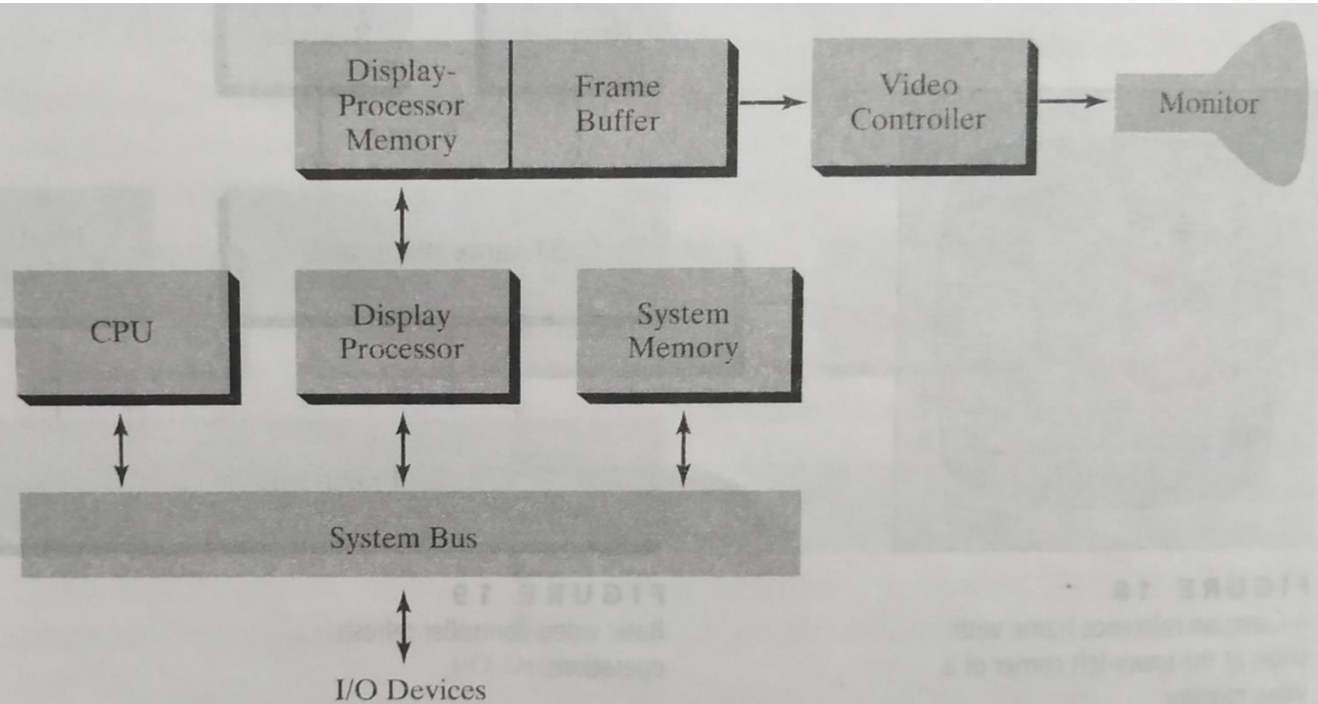


FIGURE 20
Architecture of a raster-graphics system with a display processor.

Vector Scan vs Raster Scan Display

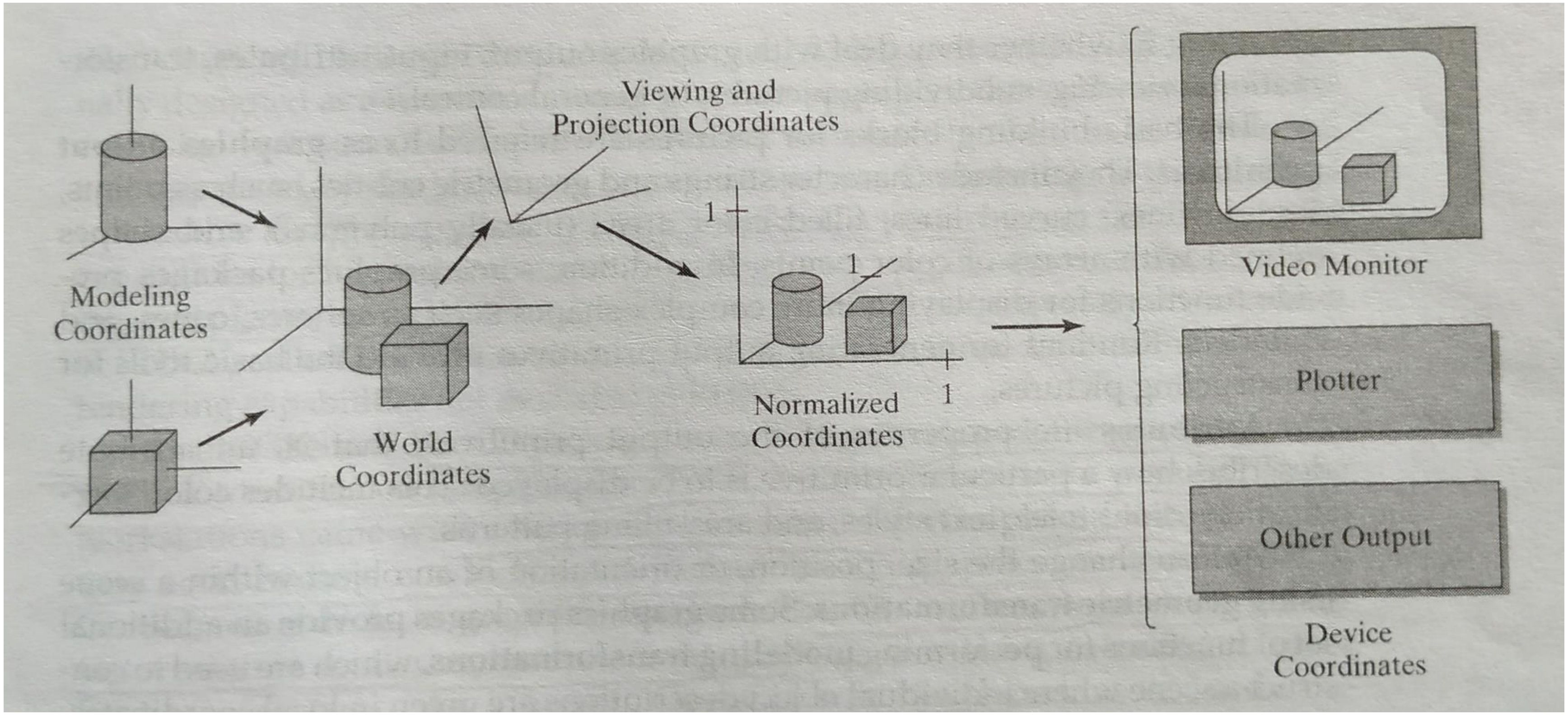
Vector Scan Display	Raster Scan Display
1. In vector scan display the beam is moved between the end points of the graphics primitives.	1. In raster scan display the beam is moved all over the screen one scan line at a time, from top to bottom and then back to top.
2. Vector display flickers when the number of primitives in the buffer becomes too large.	2. In raster display, the refresh process is independent of the complexity of the image.
3. Scan conversion is not required.	3. Graphics primitives are specified in terms of their endpoints and must be scan converted into their corresponding pixels in the frame buffer.
4. Scan conversion hardware is not required.	4. Because each primitive must be scan-converted, real time dynamics is far more computational and requires separate scan conversion hardware.
5. Vector display draws a continuous and smooth lines.	5. Raster display can display mathematically smooth lines, polygons, and boundaries of curved primitives only by approximating them with pixels on the raster grid.
6. Cost is more.	6. Cost is low.
7. Vector display only draws lines and characters.	7. Raster display has ability to display areas filled with solid colours or patterns.

4. Coordinate System

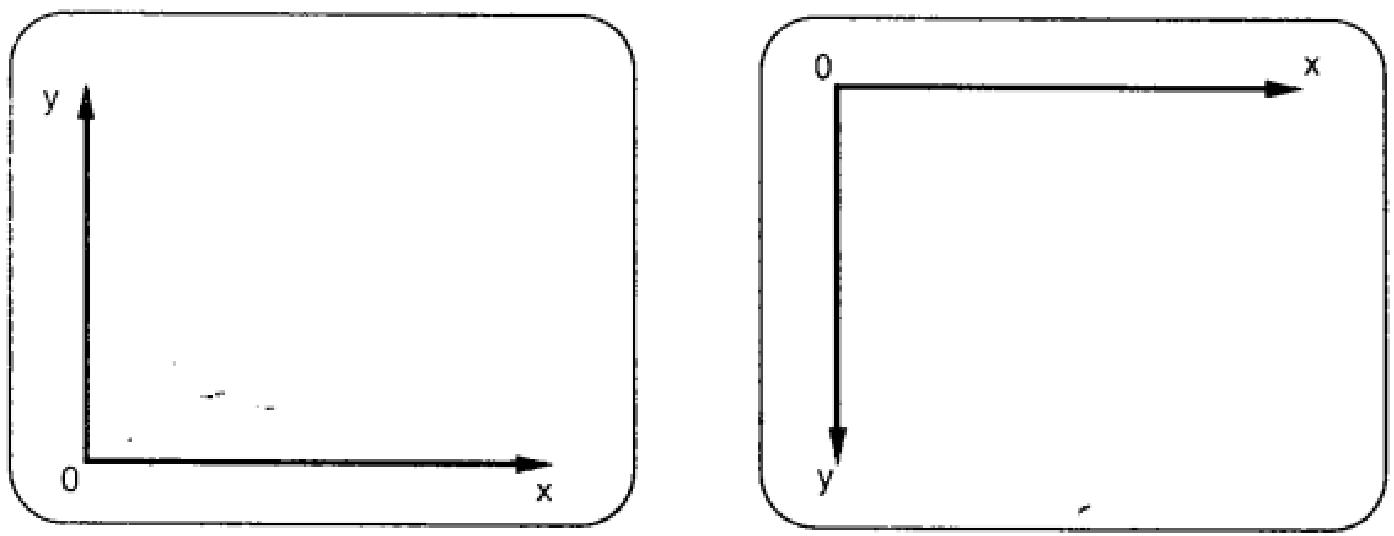
- Most of the graphics packages use Cartesian coordinate systems.

- However, in some applications non-cartesian coordinate systems such as spherical, cylindrical, or other symmetries are useful.

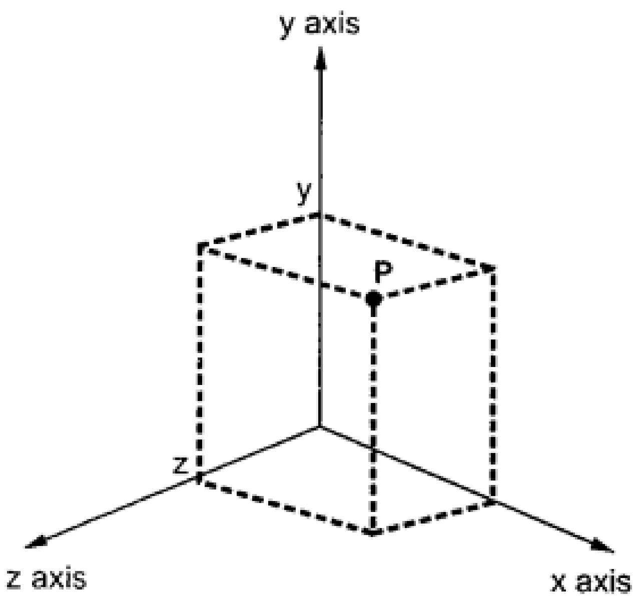
Viewing Pipeline

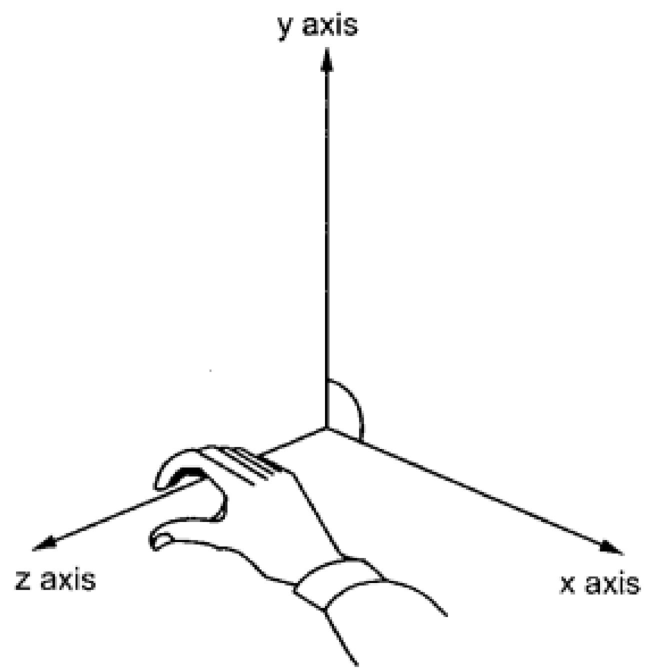


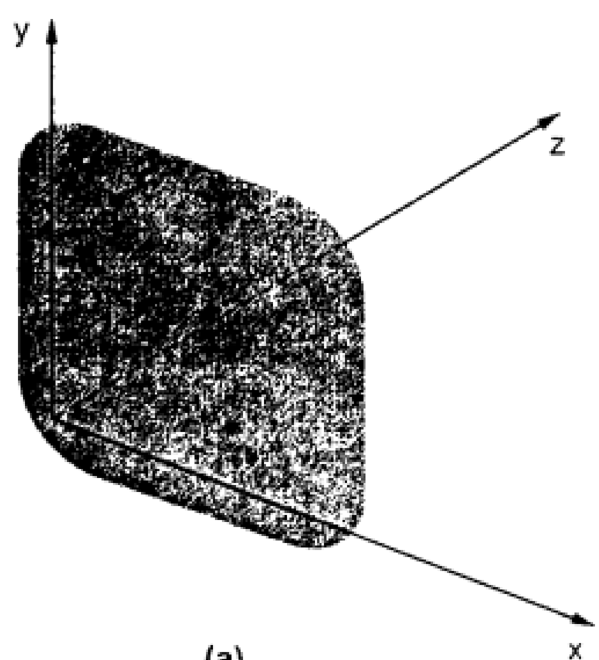
2D and 3D Coordinate Representations



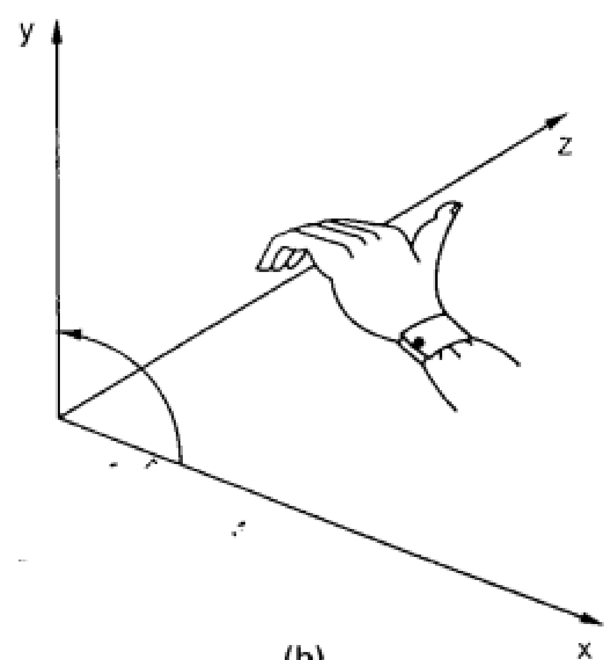
(a) (b)







(a)



(b)

Polar Coordinate Reference Frame

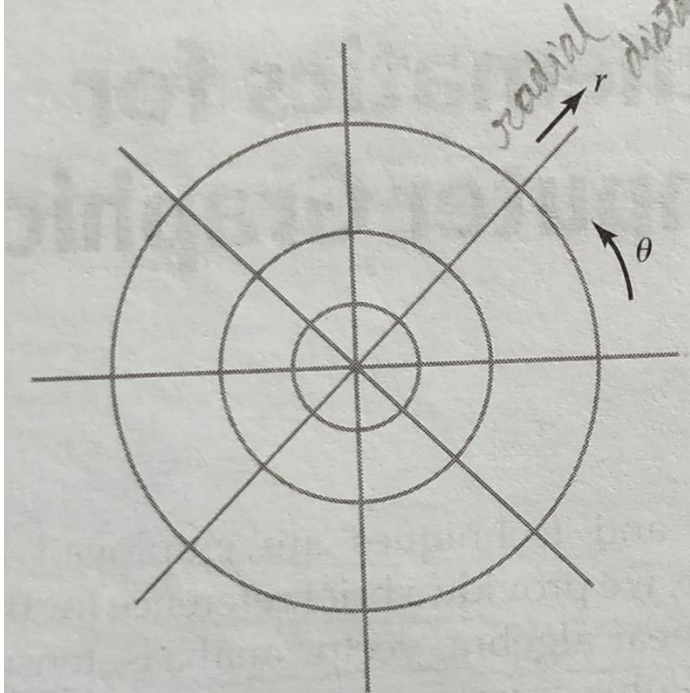


FIGURE 2
A polar-coordinate reference frame, formed with concentric circles and radial lines.

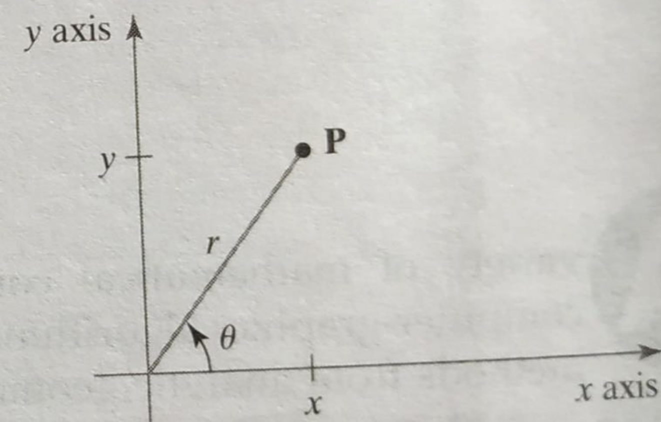
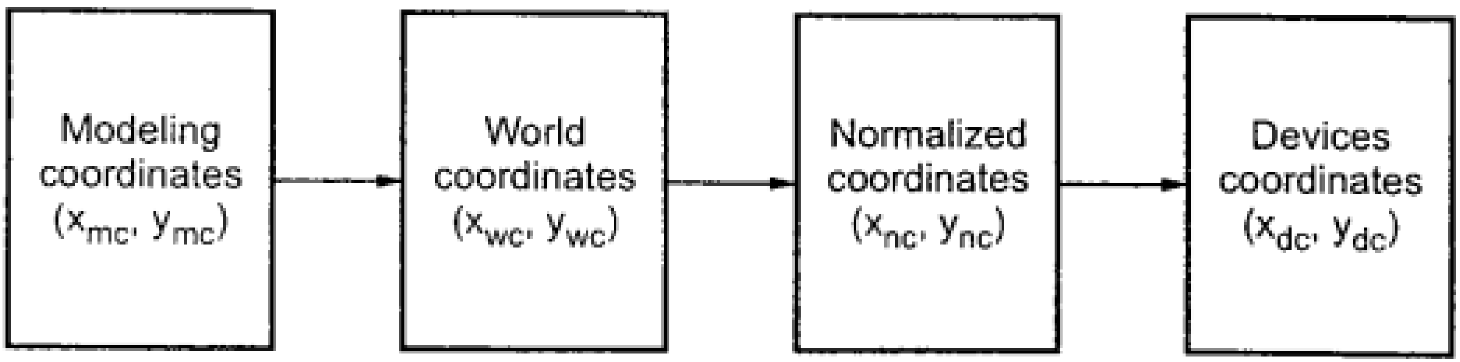


FIGURE 3
Relationship between polar and Cartesian coordinates.

Coordinate Representations



$$(x_{mc}, y_{mc}, z_{mc}) \rightarrow (x_{wc}, y_{wc}, z_{wc}) \rightarrow (x_{vc}, y_{vc}, z_{vc}) \rightarrow (x_{pc}, y_{pc}, z_{pc})$$
$$\rightarrow (x_{nc}, y_{nc}, z_{nc}) \rightarrow (x_{dc}, y_{dc})$$

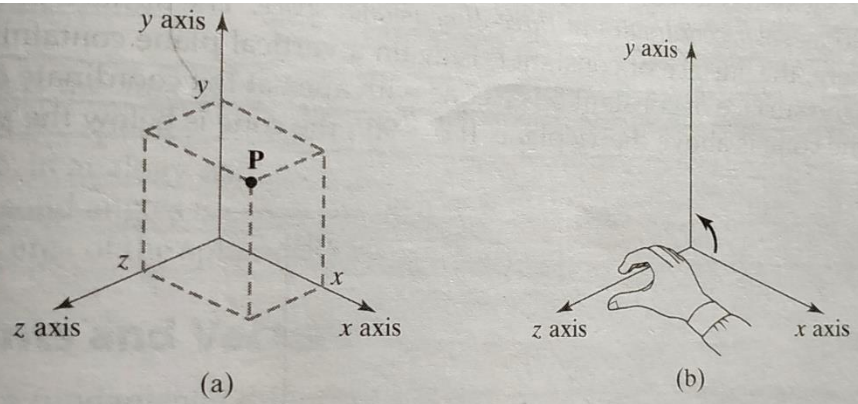


FIGURE 6
Coordinate representation for a point **P** at position (x, y, z) in a standard right-handed Cartesian reference system.

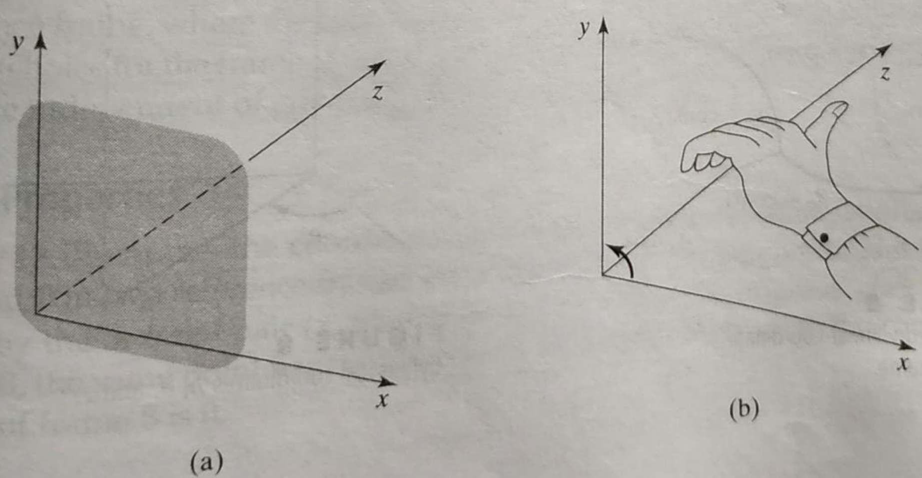


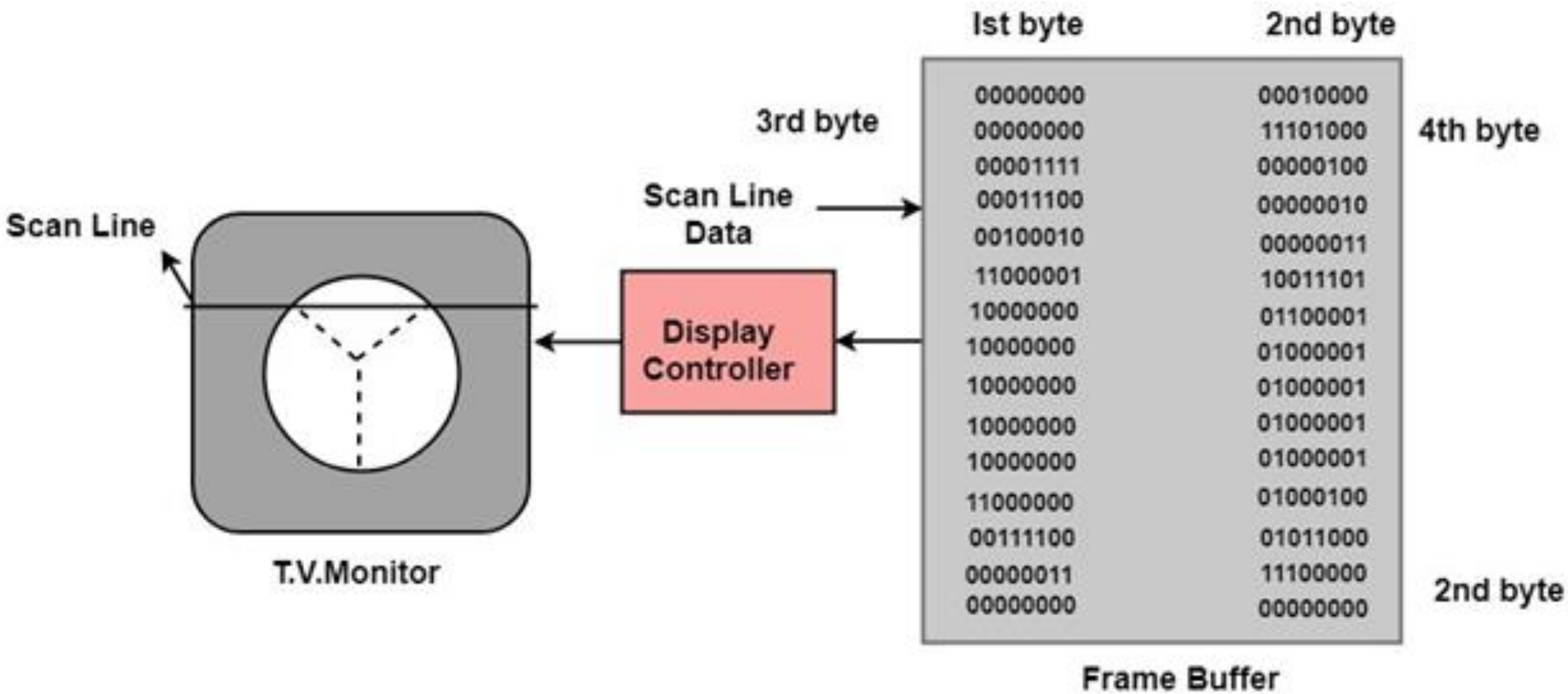
FIGURE 7
Left-handed Cartesian coordinate system superimposed on the surface of a video monitor.

Interactive and Passive Graphics

- Non-Interactive or Passive Computer Graphics:
  - In non-interactive computer graphics, the picture is produced on the monitor, and the user does not have any controlled over the image, i.e., the user cannot make any change in the rendered image. One example of its Titles shown on T.V.
  - Non-interactive Graphics involves only one-way communication between the computer and the user, User can see the produced image, and he cannot make any change in the image.

Interactive and Passive Graphics…

- Interactive Computer Graphics:
  – In interactive Computer Graphics user have some controls over the picture, i.e., the user can make any change in the produced image. One example of it is the ping-pong game.
  – Interactive Computer Graphics require two-way communication between the computer and the user. A User can see the image and make any change by sending his command with an input device.



Frame Buffer

Graphics Software and Libraries

- Software Standards:
  - The primary goal of standardized graphics software is portability.
  - When packages are designed with standard graphics functions, software can be moved easily from one hardware system to another and used in different implementations and applications.
  - Without standards, programs designed for one hardware system often cannot be transferred to another system without extensive rewriting of the programs.

- International and national standards-planning organizations in many countries have cooperated in an effort to develop a generally accepted standard for computer graphics.
- GKS in 1984
- PHIGS and PHIGS+
- SGI
- OpenGL architecture review board
- Language binding

Other Graphics Packages

- Open Inventor
- Virtual Reality Modeling Language (VRML)
- Java2D
- Java3D
- RenderMan Interface
- Mathematica
- Matlab
- Maple

Primitives: Basic Graphics Primitives

I. Scan conversion a Line.

II. Scan conversion Circle.

III. Scan conversion Ellipse.

- Filled area Primitives.

I. Scan conversion a Line

- It is a process of representing graphics objects a collection of pixels.
- The graphics objects are continuous. The pixels used are discrete. Each pixel can have either on or off state.
- The circuitry of the video display device of the computer is capable of converting binary values (0, 1) into a pixel On and pixel Off information. 0 is represented by pixel off. 1 is represented using pixel on. Using this ability graphics computer represent picture having discrete dots.
- Any model of graphics can be reproduced with a dense matrix of dots or points. Most human beings think graphics objects as points, lines, circles, ellipses. For generating graphical object, many algorithms have been developed.

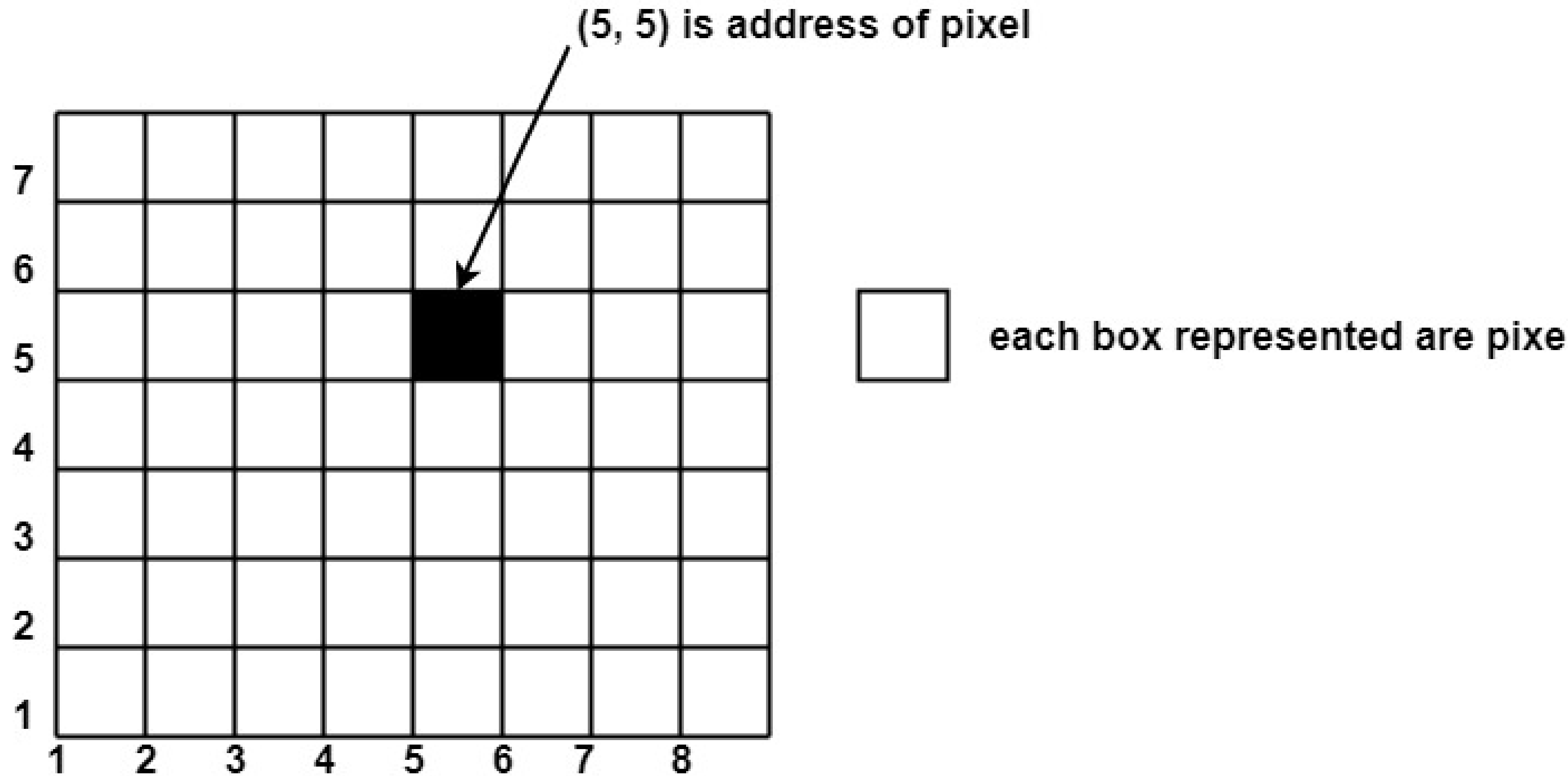
Advantages for scan conversion a line

- Algorithms can generate graphics objects at a faster rate.
- Using algorithms memory can be used efficiently.
- Algorithms can develop a higher level of graphical objects.

Pixel or Pel

- The term pixel is a short form of the picture element. It is also called a point or dot. It is the smallest picture unit accepted by display devices.
- A picture is constructed from hundreds of such pixels. Pixels are generated using commands. Lines, circle, arcs, characters; curves are drawn with closely spaced pixels. To display the digit or letter matrix of pixels is used.
- The closer the dots or pixels are, the better will be the quality of picture. Closer the dots are, crisper will be the picture.
- Picture will not appear jagged and unclear if pixels are closely spaced. So the quality of the picture is directly proportional to the density of pixels on the screen.

Pixel or Pel…



(5, 5) is address of pixel
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
each box represented are pixel

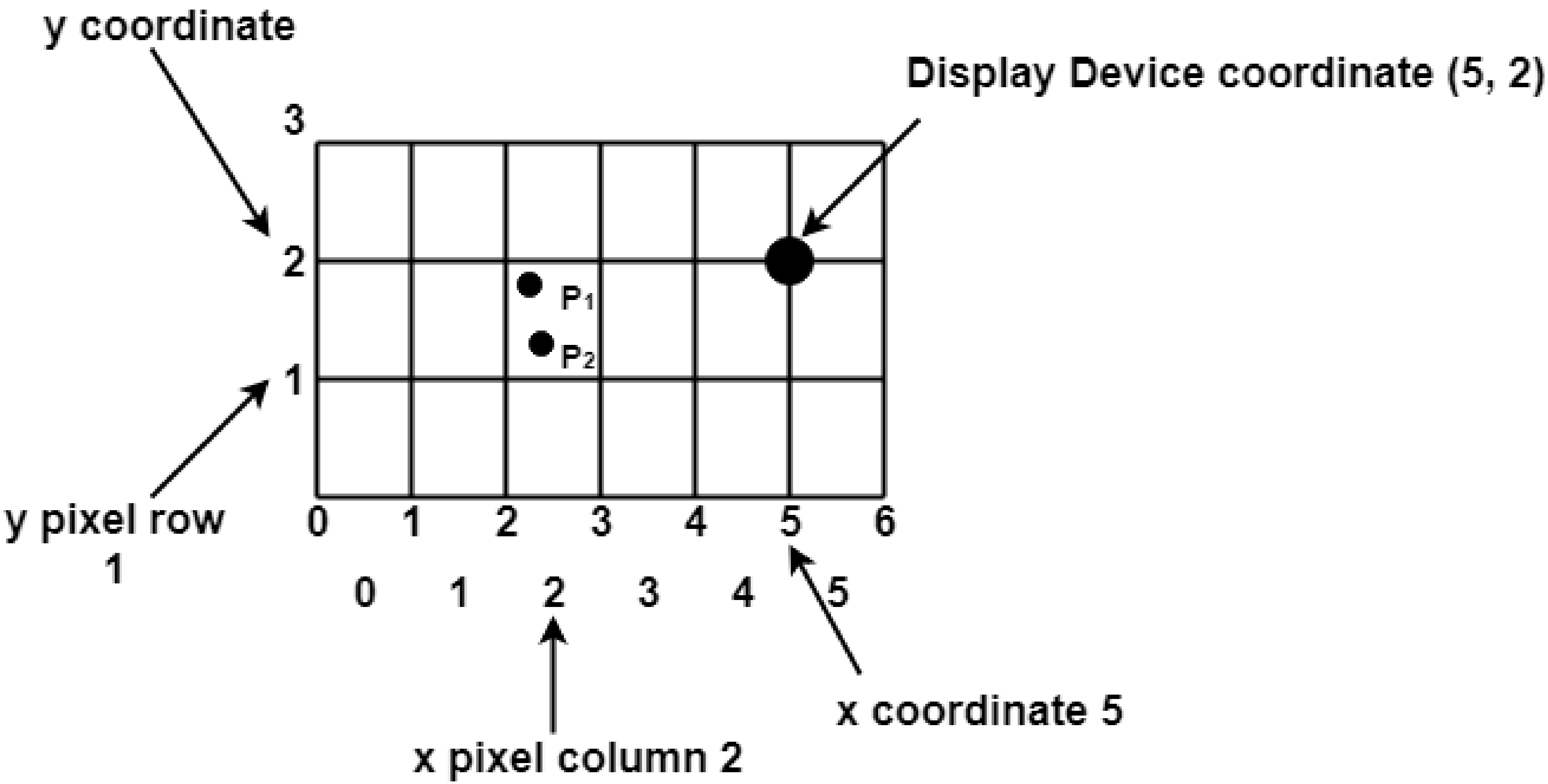
Pixel or Pel…

- Different graphics objects can be generated by setting the different intensity of pixels and different colors of pixels. Each pixel has some co-ordinate value. The coordinate is represented using row and column.
- P (5, 5) used to represent a pixel in the 5th row and the 5th column. Each pixel has some intensity value which is represented in memory of computer called a **frame buffer**.
- Frame Buffer is also called a refresh buffer. This memory is a storage area for storing pixels values using which pictures are displayed. It is also called as digital memory.
- Inside the buffer, image is stored as a pattern of binary digits either 0 or 1. So there is an array of 0 or 1 used to represent the picture. In black and white monitors, black pixels are represented using 1's and white pixels are represented using 0's. In case of systems having one bit per pixel frame buffer is called a bitmap. In systems with multiple bits per pixel it is called a pixmap.

Scan converting a Point

- Each pixel on the graphics display does not represent a mathematical point.
- Instead, it means a region which theoretically can contain an infinite number of points.
- Scan-Converting a point involves illuminating the pixel that contains the point.

Scan converting a Point…



Scan converting a Straight Line

- A straight-line segment in a scene is defined by the coordinate positions for the endpoints of the segment.
- To display the line on a raster monitor, the graphics system must first project the endpoints to integer screen coordinates and determine the nearest pixel positions along the line path between the two endpoints.
- Then the line color is loaded into the frame buffer at the corresponding pixel coordinates.

Scan converting a Straight Line…

- Reading from the frame buffer, the video controller plots the screen pixels.
- This process digitizes the line into a set of discrete integer positions that, in general, only approximates the actual line path.

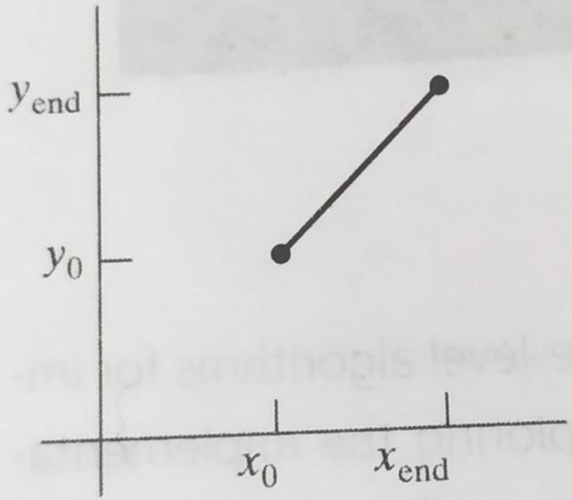


FIGURE 2
Line path between endpoint positions (x_0, y_0) and (x_{end}, y_{end}).

$$y = m \cdot x + b$$

and b as the y intercept.
ed at positions (x_0, y_0)
values for the slope m

$$m = \frac{y_{end} - y_0}{x_{end} - x_0}$$

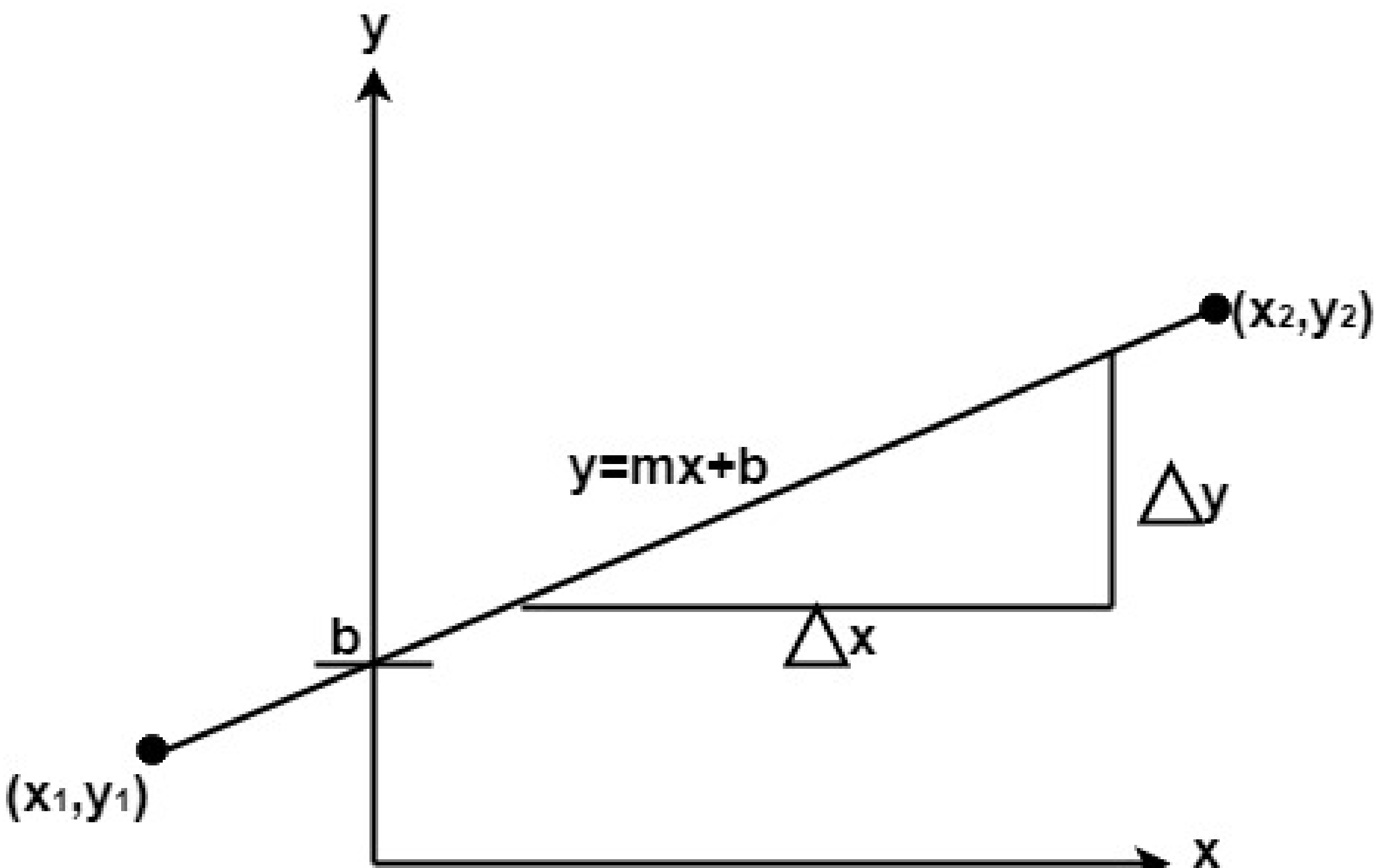
$$b = y_0 - m \cdot x_0$$

straight lines are based
and 3.
l δx along a line, we can
n 2 as

$$\delta y = m \cdot \delta x$$

x interval δx correspond

$$\delta x = \frac{\delta y}{m}$$


y
(x_2,y_2)
y=mx+b
Δy
b
Δx
(x_1,y_1)
x

Line Equations

- We determine pixel positions along a straight-line path from the geometric properties of the line.
- The Cartesian slope-intercept equation for a straight-line is: $y = m.x + b$

Properties of Good Line Drawing Algo.:

- Line should appear Straight.
- Lines should terminate accurately.
- Lines should have constant density.
- Line density should be independent of line length and angle.
- Line should be drawn rapidly.

Fig: O/P from a poor line generating algorithm

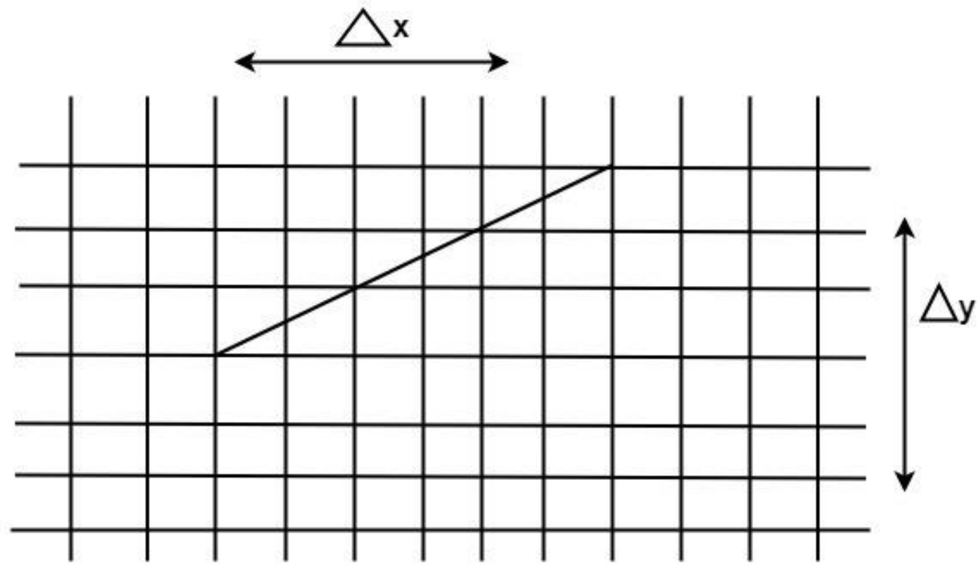


Fig: A straight line segment connecting 2 grid intersection may fail to pass through any other grid intersections.

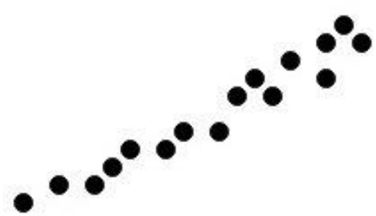
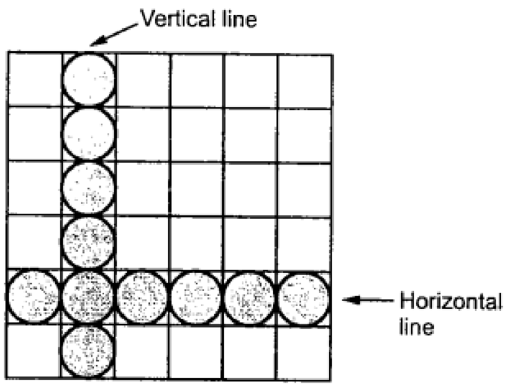


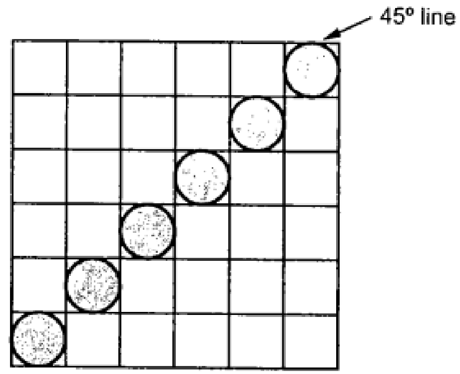
Fig: Uneven line density caused by bunching of dots.

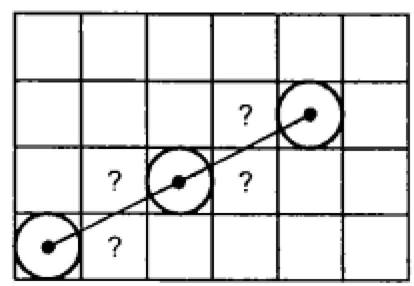
Algorithms for Line drawing

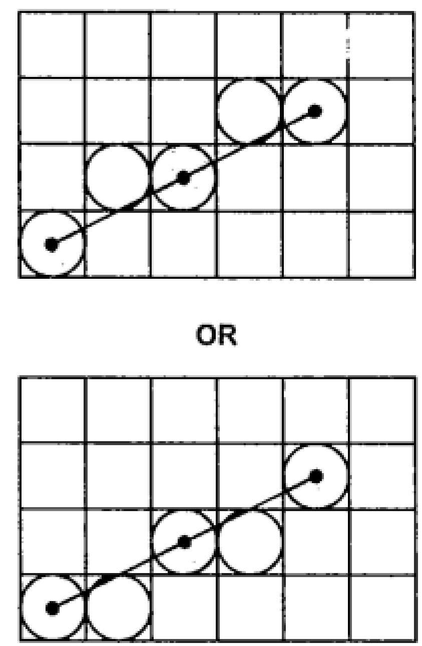
- Direct use of line equation.
- Digital Differential Analyzer (DDA).
- Bresenham’s Algorithm.

Basic concept of Line drawing









Direct use of Line Equation

- It is the simplest form of conversion. First of all scan P_1 and P_2 points. P_1 has co-ordinates (x_1',y_1') and $(x_2'\ y_2')$.
- Then m = $(y_2',y_1')/(x_2',x_1')$ and $b = y_1^1 + mx_1^1$
- If value of $|m|\leq 1$ for each integer value of x. But do not consider x_1^1 and x_2^2
- If value of $|m|>1$ for each integer value of y. But do not consider y_1^1 and y_2^2

Algorithm for drawing line using equation

- **Step1:** Start Algorithm
- **Step2:** Declare variables x_1,x_2,y_1,y_2,dx,dy,m,b,
- **Step3:** Enter values of x_1,x_2,y_1,y_2.
  The (x_1,y_1) are co-ordinates of a starting point of the line.
  The (x_2,y_2) are co-ordinates of a ending point of the line.
- **Step4:** Calculate dx = x_2- x_1
- **Step5:** Calculate dy = y_2-y_1
- **Step6:** Calculate m = $\frac{dy}{dx}$
- **Step7:** Calculate b = y_1-m* x_1

- **Step8:** Set (x, y) equal to starting point, i.e., lowest point and x_{end} equal to largest value of x.
- If $dx < 0$
  then $x = x_2$
  $y = y_2$
  $x_{end} = x_1$
  If $dx > 0$
  then $x = x_1$
  $y = y_1$
  $x_{end} = x_2$
- **Step9:** Check whether the complete line has been drawn if $x=x_{end}$, stop
- **Step10:** Plot a point at current (x, y) coordinates
- **Step11:** Increment value of x, i.e., $x = x+1$
- **Step12:** Compute next value of y from equation $y = mx + b$
- **Step13:** Go to Step9.

- **Example:** A line with starting point as (0, 0) and ending point (6, 18) is given. Calculate value of intermediate points and slope of line.
- **Solution:** P_1 (0,0) P_7 (6,18)
- $x_1=0$
  $y_1=0$
  $x_2=6$
  $y_2=18$

- We know equation of line is
  $y = m x + b$
  $y = 3x + b$..............equation (1)
- put value of x from initial point in equation (1), i.e., (0, 0) x =0, y=0
  $0 = 3 \times 0 + b$
  $0 = b \Longrightarrow b=0$
- put b = 0 in equation (1)

- $y = 3x + 0$

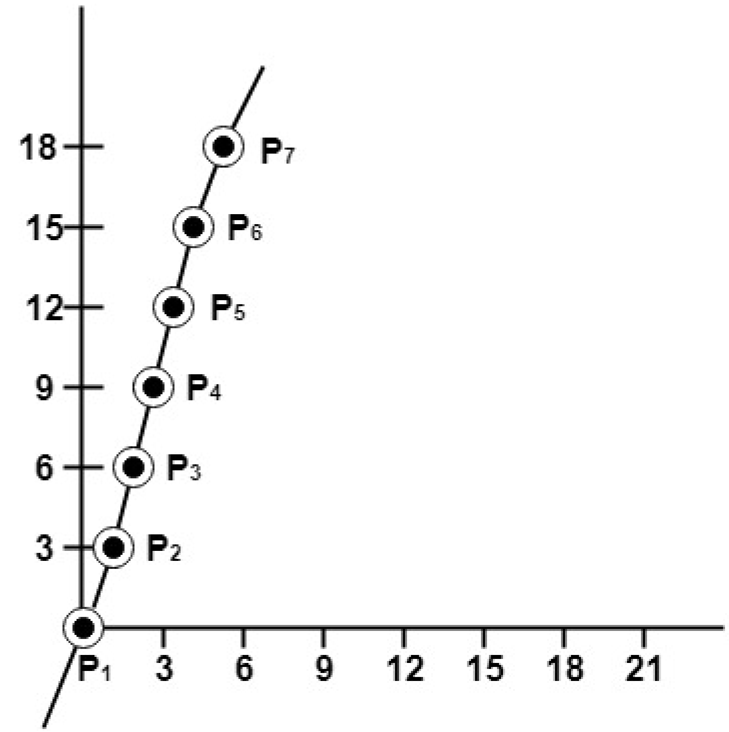
  $y = 3x$

- Now calculate intermediate points

  Let $x = 1 \Longrightarrow y = 3 \times 1 \Longrightarrow y = 3$
  Let $x = 2 \Longrightarrow y = 3 \times 2 \Longrightarrow y = 6$
  Let $x = 3 \Longrightarrow y = 3 \times 3 \Longrightarrow y = 9$
  Let $x = 4 \Longrightarrow y = 3 \times 4 \Longrightarrow y = 12$
  Let $x = 5 \Longrightarrow y = 3 \times 5 \Longrightarrow y = 15$
  Let $x = 6 \Longrightarrow y = 3 \times 6 \Longrightarrow y = 18$

- So points are P_1 (0,0)

  P_2 (1,3)
  P_3 (2,6)
  P_4 (3,9)
  P_5 (4,12)
  P_6 (5,15)
  P_7 (6,18)



Direct Differential Analyzer (DDA)

- DDA stands for Digital Differential Analyzer.
- It is an incremental method of scan conversion of line. In this method calculation is performed at each step but by using results of previous steps.
- The DDA is a scan-conversion line algorithm based on calculating either $^{\delta}y$ and $^{\delta}x$, using line equations.

DDA Algorithm

1. Read the line end points (x_1, y_1) and (x_2, y_2) such that they are not equal.
   [if equal then plot that point and exit]
2. $\Delta x = |x_2 - x_1|$ and $\Delta y = |y_2 - y_1|$
3. if $(\Delta x \geq \Delta y)$ then
       length = Δx
   else
       length = Δy
   end if
4. $\Delta x = (x_2 - x_1)$ / length
   $\Delta y = (y_2 - y_1)$ / length
   [This makes either Δx or Δy equal to 1 because length is either $|x_2 - x_1|$ or $|y_2 - y_1|$. Therefore, the incremental value for either x or y is one.]
5. $x = x_1 + 0.5 * \text{Sign}(\Delta x)$
   $y = y_1 + 0.5 * \text{Sign}(\Delta y)$
   [Here, Sign function makes the algorithm work in all quadrant. It returns - 1, 0, 1 depending on whether its argument is < 0, = 0, > 0 respectively. The factor 0.5 makes it possible to round the values in the integer function rather than truncating them.]
6. i = 1 [Begins the loop, in this loop points are plotted]
   While (i ≤ length)
   {
       Plot (Integer (x), Integer (y))
       $x = x + \Delta x$
       $y = y + \Delta y$
       i = i + 1
7. Stop

Advantages of DDA

- Advantages:
  - It is a faster method than method of using direct use of line equation.
  - This method does not use multiplication theorem.
  - It allows us to detect the change in the value of x and y, so plotting of same point twice is not possible.
  - This method gives overflow indication when a point is repositioned.
  - It is an easy method because each step involves just two additions.

Disadvantages of DDA

- Disadvantages:
  - It involves floating point additions rounding off is done. Accumulations of round off error cause accumulation of error.
  - Rounding off operations and floating point operations consumes a lot of time.
  - It is more suitable for generating line using the software. But it is less suited for hardware implementation.

- **Example:** If a line is drawn from (2, 3) to (6, 15) with use of DDA. How many points will needed to generate such line?
- **Solution:** P_1 (2,3) P_{11} (6,15)
- $x_1=2$
  $y_1=3$
  $x_2= 6$
  $y_2=15$
  dx = 6 - 2 = 4
  dy = 15 - 3 = 12
  m =
- For calculating next value of x takes x = x + 1/m
-

$P_1(2, 3)$ point plotted

$P_2(2\frac{1}{3}, 4)$ point plotted

$P_3(2\frac{2}{3}, 5)$ point not plotted

$P_4(3, 6)$ point plotted

$P_5(3\frac{1}{3}, 7)$ point not plotted

$P_6(3\frac{2}{3}, 8)$ point not plotted

$P_7(4, 9)$ point plotted

$P_8(4\frac{1}{3}, 10)$ point not plotted

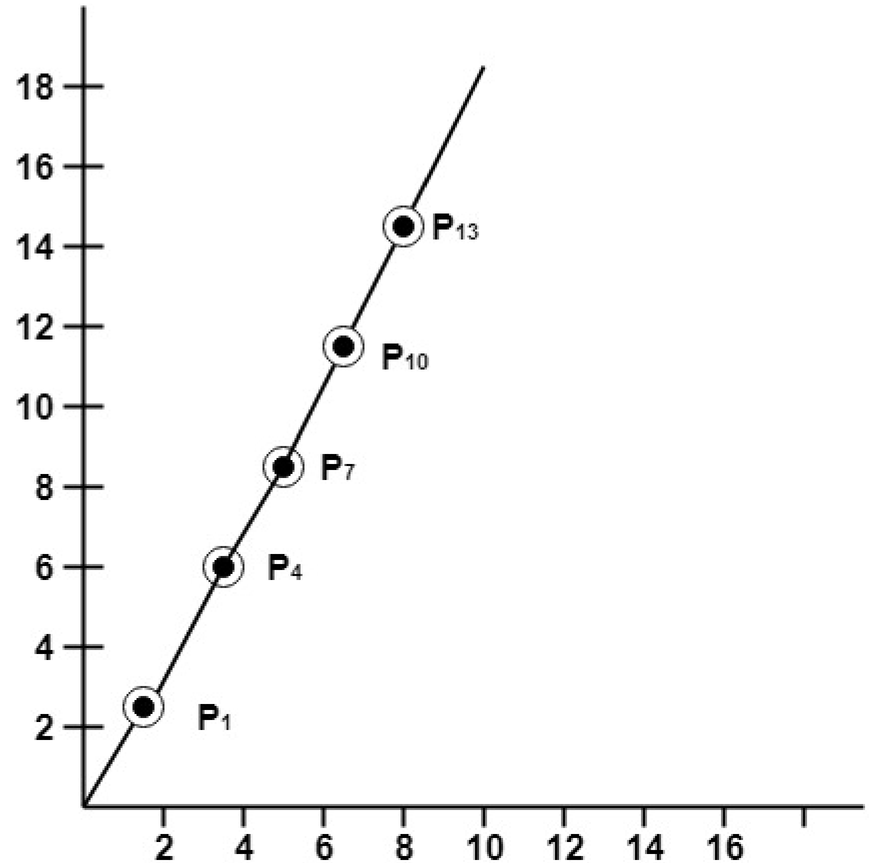
$P_9(4\frac{2}{3}, 11)$ point not plotted

$P_{10}(5, 12)$ point plotted

$P_{11}(5\frac{1}{3}, 13)$ point not plotted

$P_{12}(5\frac{2}{3}, 14)$ point not plotted

$P_{13}(6, 15)$ point plotted



Problems of DDA

- Consider the line from (0,0) to (4,6). Use the simple DDA algorithm to rasterize this line segment.

- Consider the line from (0,0) to (-6,-6). Use the simple DDA algorithm to rasterize this line segment.

Bresenham's Line Drawing Algorithm

- This algorithm is used for scan converting a line.
- It was developed by Bresenham.
- It is an efficient method because it involves only integer addition, subtractions, and multiplication operations. These operations can be performed very rapidly so lines can be generated quickly.
- In this method, next pixel selected is that one who has the least distance from true line.

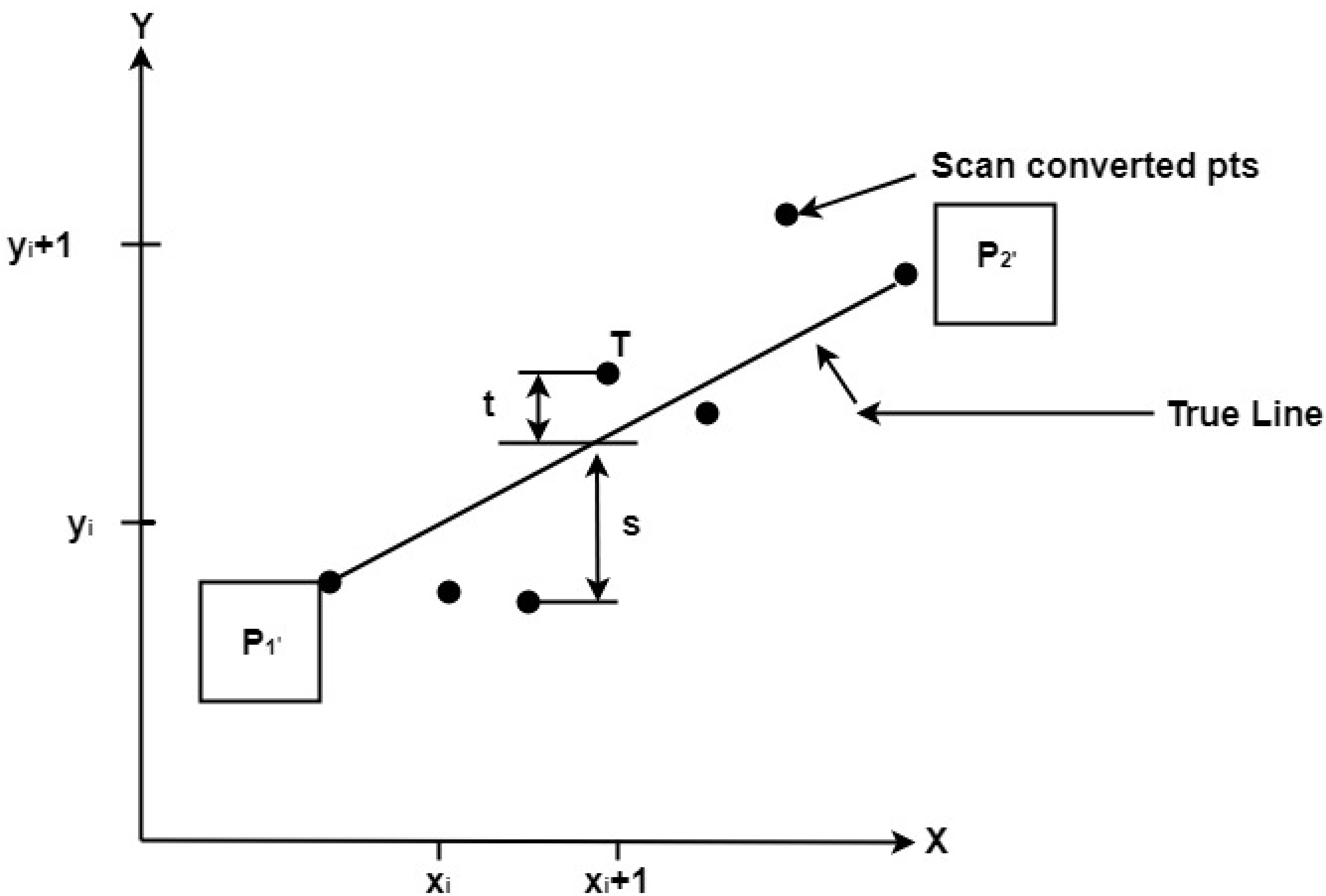
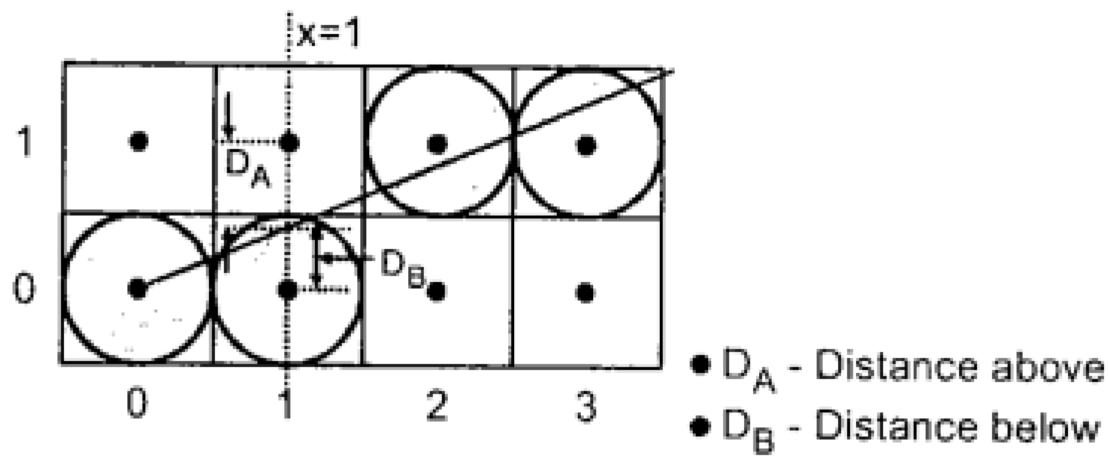


Fig: Scan Converting a line.



x=1
1
0
D_A
D_B
0
1
2
3
● D_A - Distance above
● D_B - Distance below

Bresenham's Algorithm

1. Read the line end points (x_1, y_1) and (x_2, y_2) such that they are not equal.
   [if equal then plot that point and exit]
2. $\Delta x = |x_2 - x_1|$ and $\Delta y = |y_2 - y_1|$
3. [Initialize starting point]
   $x = x_1$
   $y = y_1$
4. $e = 2 * \Delta y - \Delta x$
   [Initialize value of decision variable or error to compensate for nonzero intercepts]
5. $i = 1$ [Initialize counter]
6. Plot (x, y)
7. while ($e \geq 0$)

```
{
    y = y + 1
    e = e – 2 * Δx
}
x = x + 1
e = e + 2 * Δy
```

8. $i = i + 1$
9. if ($i \leq \Delta x$) then go to step 6.
10. Stop

Advantages of Bresenham’s Algorithm

- Advantages:
  - It involves only integer arithmetic, so it is simple.
  - It avoids the generation of duplicate points.
  - It can be implemented using hardware because it does not use multiplication and division.
  - It is faster as compared to DDA (Digital Differential Analyzer) because it does not involve floating point calculations like DDA Algorithm.

Disadvantages of Bresenham’s Algorithm

- Disadvantages:
  - This algorithm is meant for basic line drawing only Initializing is not a part of Bresenham's line algorithm. So to draw smooth lines, you should want to look into a different algorithm.

- **Example:** Starting and Ending position of the line are (1, 1) and (8, 5). Find intermediate points.
- **Solution:** $x_1=1$

  $y_1=1$

  $x_2=8$

  $y_2=5$

  $dx= x_2-x_1=8-1=7$

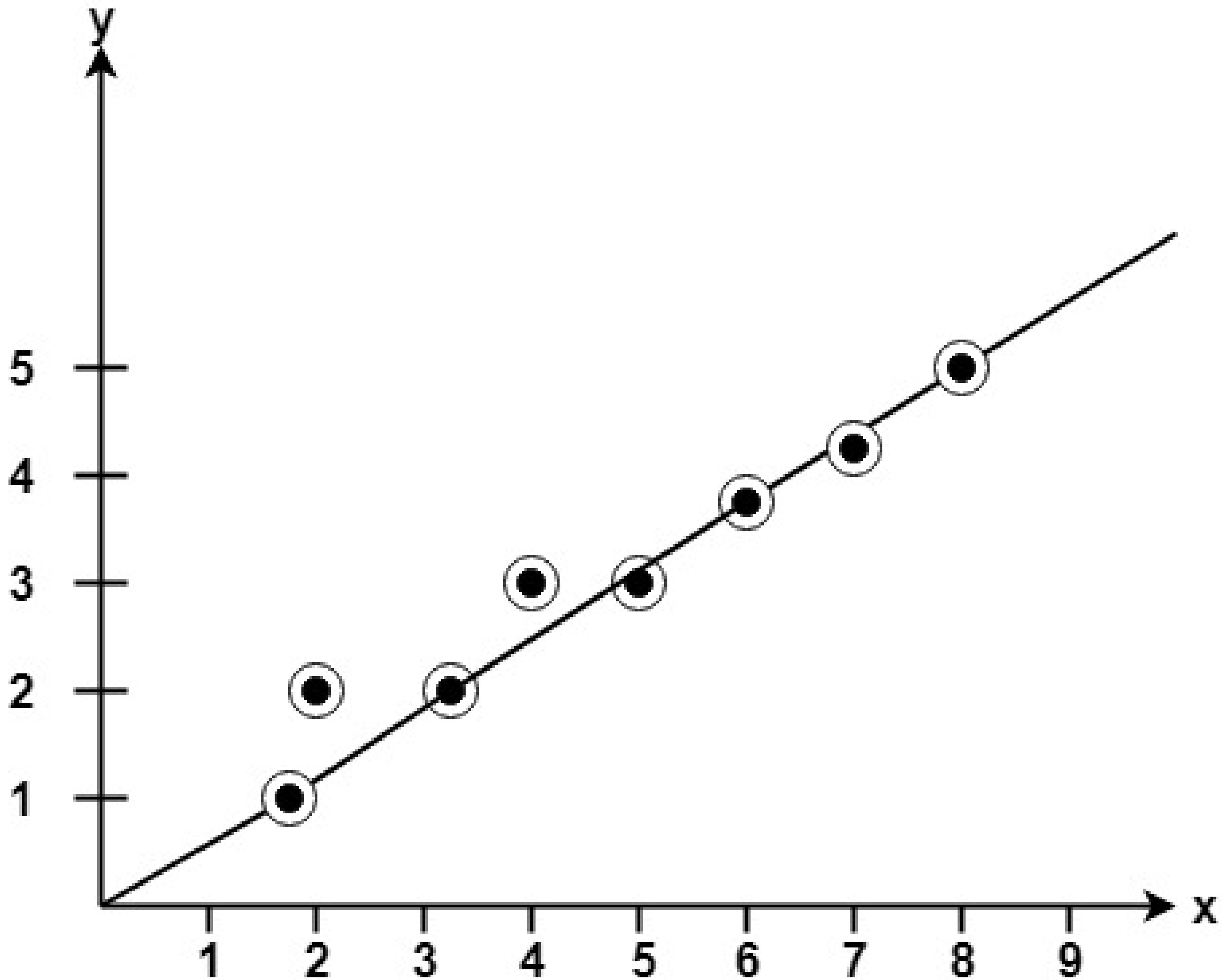
  $dy=y_2-y_1=5-1=4$

  $I_1=2* \Delta y=2*4=8$

  $I_2=2*(\Delta y-\Delta x)=2*(4-7)=-6$

  $d = I_1-\Delta x=8-7=1$

x	y	$d=d+I_1$ or I_2
1	1	$d+I_2=1+(-6)=-5$
2	2	$d+I_1=-5+8=3$
3	2	$d+I_2=3+(-6)=-3$
4	3	$d+I_1=-3+8=5$
5	3	$d+I_2=5+(-6)=-1$
6	4	$d+I_1=-1+8=7$
7	4	$d+I_2=7+(-6)=1$
8	5	



y
5
4
3
2
1
x
1
2
3
4
5
6
7
8
9

Difference Between DDA and Bresenham’s Line Algorithms

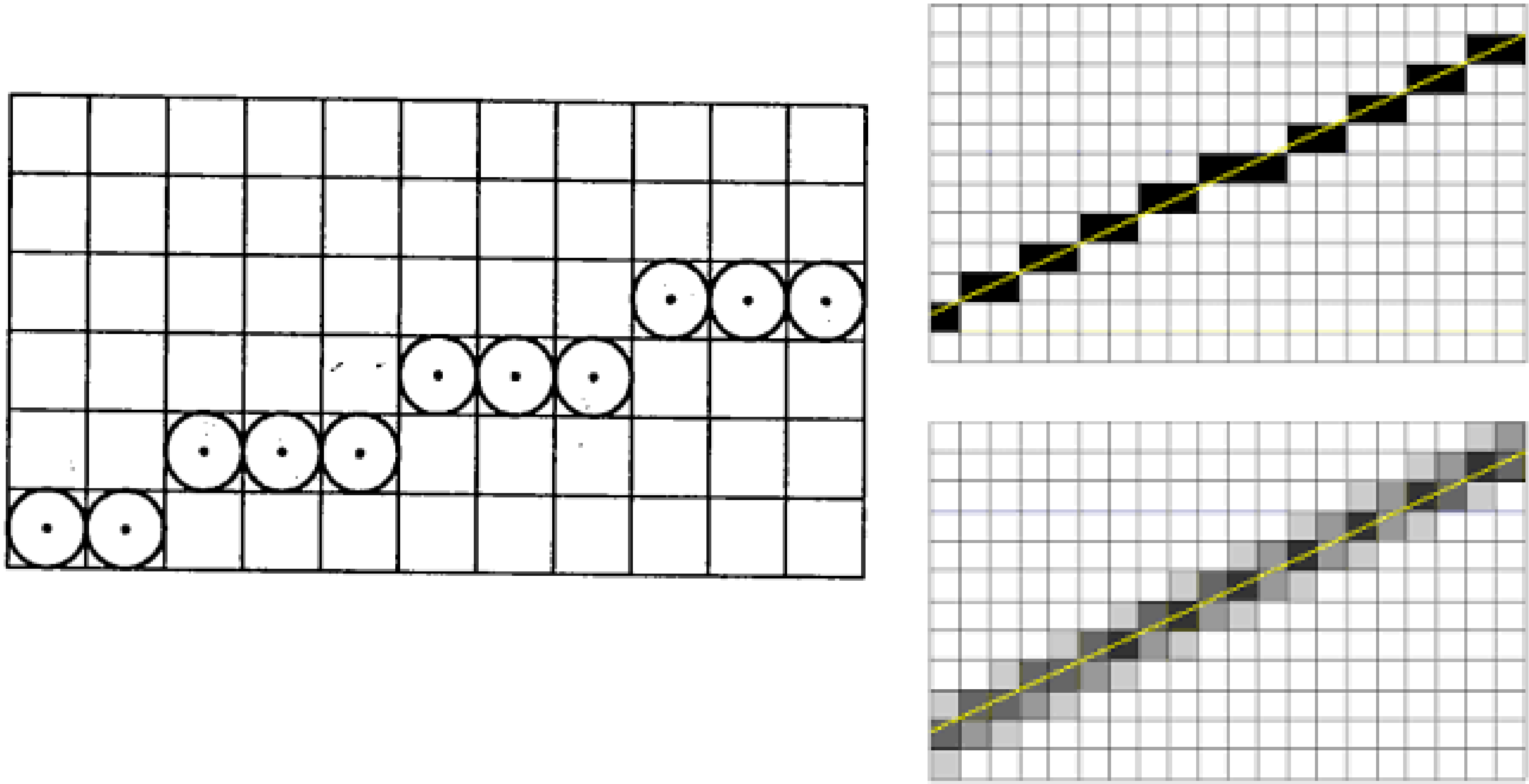
DDA Algorithm	Bresenham's Line Algorithm
1. DDA Algorithm use floating point, i.e., Real Arithmetic.	1. Bresenham's Line Algorithm use fixed point, i.e., Integer Arithmetic
2. DDA Algorithms uses multiplication & division its operation	2.Bresenham's Line Algorithm uses only subtraction and addition its operation
3. DDA Algorithm is slowly than Bresenham's Line Algorithm in line drawing because it uses real arithmetic (Floating Point operation)	3. Bresenham's Algorithm is faster than DDA Algorithm in line because it involves only addition & subtraction in its calculation and uses only integer arithmetic.
4. DDA Algorithm is not accurate and efficient as Bresenham's Line Algorithm.	4. Bresenham's Line Algorithm is more accurate and efficient at DDA Algorithm.
5.DDA Algorithm can draw circle and curves but are not accurate as Bresenham's Line Algorithm	5. Bresenham's Line Algorithm can draw circle and curves with more accurate than DDA Algorithm.

Antialiasing of Lines

- In the line drawing algorithm, we have seen that all rasterized locations do not match with the true line and we have to select the optimum raster locations to represent a straight line.

- This problem is severe in low resolution screens. In such screens line appears like a stair-step.

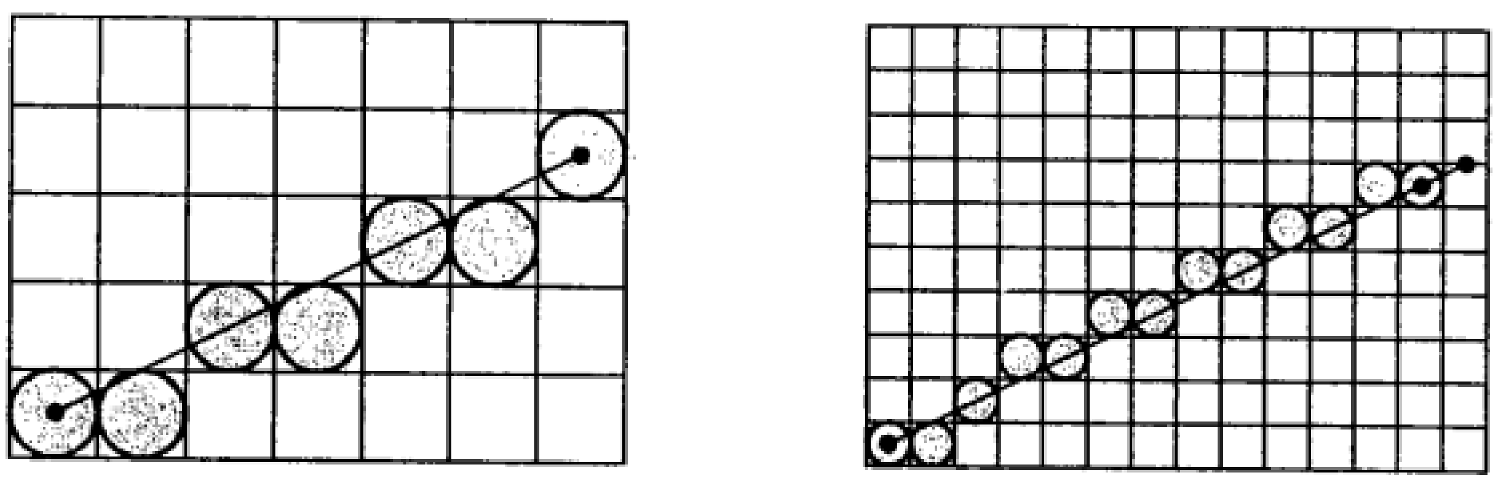
- The aliasing effect is the appearance of jagged edges or “jaggies” in a rasterized image (an image rendered using pixels).



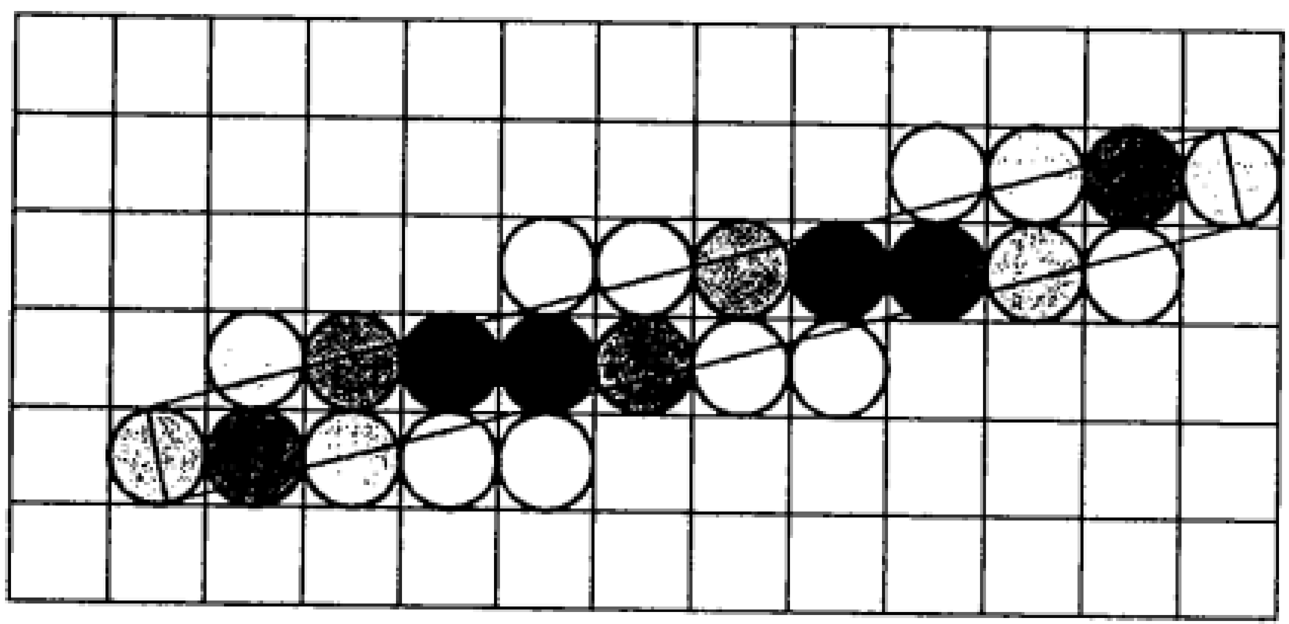
- The problem of jagged edges technically occurs due to distortion of the image when scan conversion is done with sampling at a low frequency, which is also known as Undersampling.
- Aliasing occurs when real-world objects which comprise of smooth, continuous curves are rasterized using pixels.
- **Antialiasing** is a technique used in computer graphics to remove the aliasing effect.
- The aliasing effect can be reduced by adjusting intensities of the pixels along the line.
- The process of adjusting intensities of the pixels along the line to minimize the effect of aliasing is called antialiasing.

Methods of Antialiasing:

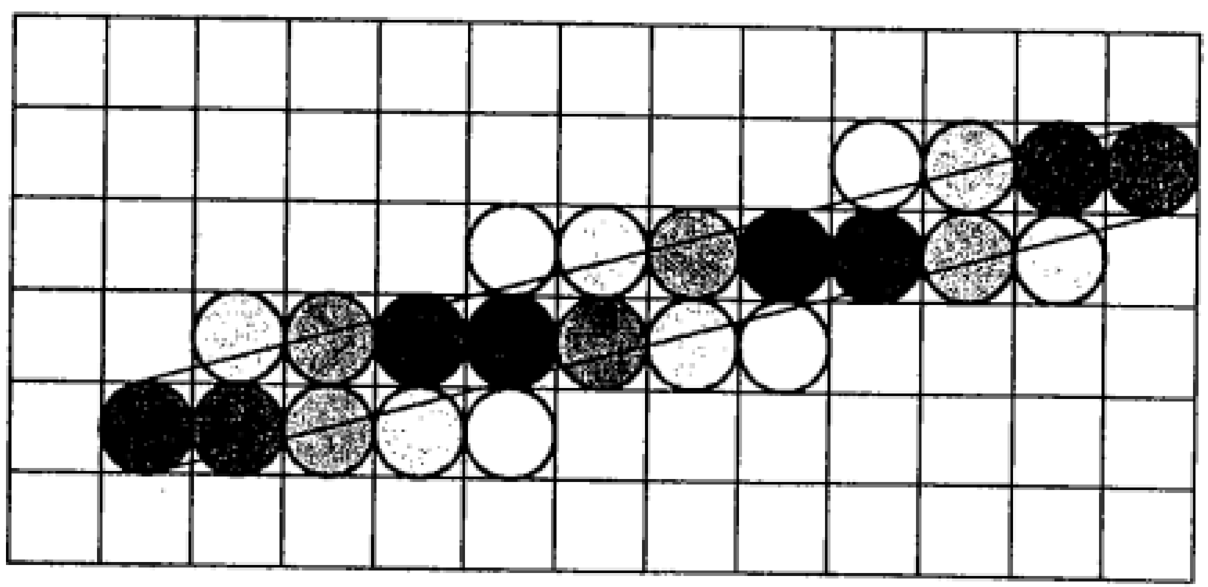
- **Increasing resolution:**



- **Unweighted area sampling:** The intensity of pixel is proportional to the amount of line area occupied by the pixel. This technique produces noticeably better results than does setting pixels either to full intensity or to zero intensity.



- **Weighted area sampling:** in weighted area sampling equal areas contribute unequally i.e. a small area closer to the pixel center has greater intensity than does one at a greater distance. Thus, the intensity of the pixel is dependent on the line area occupied and the distance of area from the pixel's center.



Displaying Polylines

- Implementation of a polyline procedure is accomplished by invoking a line-drawing routine *n-1* times to display the line connecting the *n* endpoints.
- Each successive call passes the coordinate pair needed to plot the next line section, where the first endpoint of each coordinate pair is the last endpoint of the previous section.
- Once the color values for pixel positions along the first line segment have been set in the frame buffer, we process subsequent line segments starting with the next pixel position following the first endpoint for that segment.
- In this way, we can avoid setting the color of some endpoints twice.

Parallel Line Algorithms

- Using parallel processing, we can calculate multiple pixel positions along a line path simultaneously by partitioning the computations among the various processors available.
- One approach to the partitioning problem is to adapt an existing sequential algorithm to take advantage of multiple processors.
- Alternatively, to set up the processing so that pixel positions can be calculated efficiently in parallel.
- An important consideration in devising a parallel algorithm is to balance the processing load among the available processors.

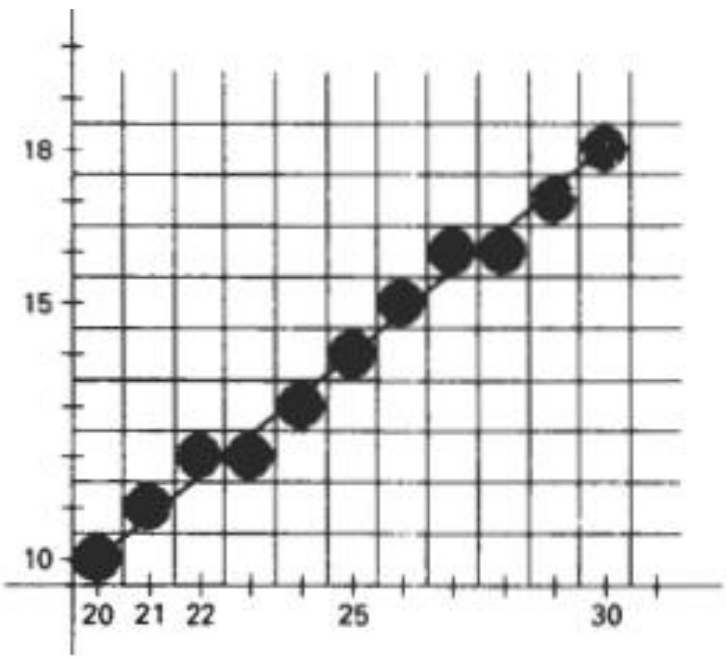


Figure 3-9
Pixel positions along the line path between endpoints (20, 10) and (30, 18), plotted with Bresenham's line algorithm.

- Given n_p processors, we can set up a parallel Bresenham line algorithm by subdividing the line path into n_p partitions and simultaneously generating line segments in each of the subintervals.
- For a line with slope *0 < m < 1* and left endpoint coordinate position (x0, y0), we partition the line along the positive x direction.
- The distance between beginning x positions of adjacent partitions can be calculated as:

$$\Delta x_p = \frac{\Delta x + n_p - 1}{n_p}$$

- Numbering the partitions, and the processors, as 0,1,2, up to n_p-1, we calculate the starting x coordinate for the *k*th partition as: $x_k = x_0 + k\Delta x_p$

Scan Conversion Circle

- A circle is defined as the set of points that are all at a given distance r from a center position.
- Circle is an eight-way symmetric figure.
- The shape of circle is the same in all quadrants. In each quadrant, there are two octants.
- If the calculation of the point of one octant is done, then the other seven points can be calculated easily by using the concept of eight-way symmetry.

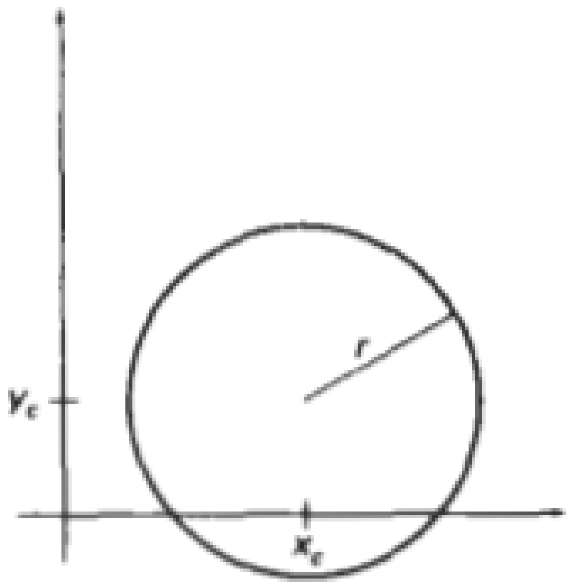
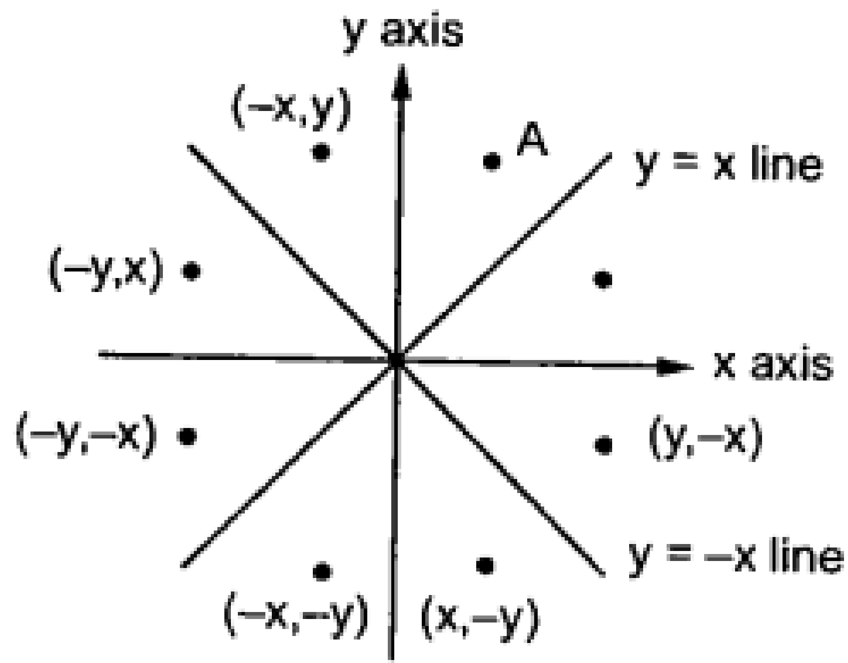


Figure 3-12
Circle with center coordinates (x_c, y_c) and radius r.



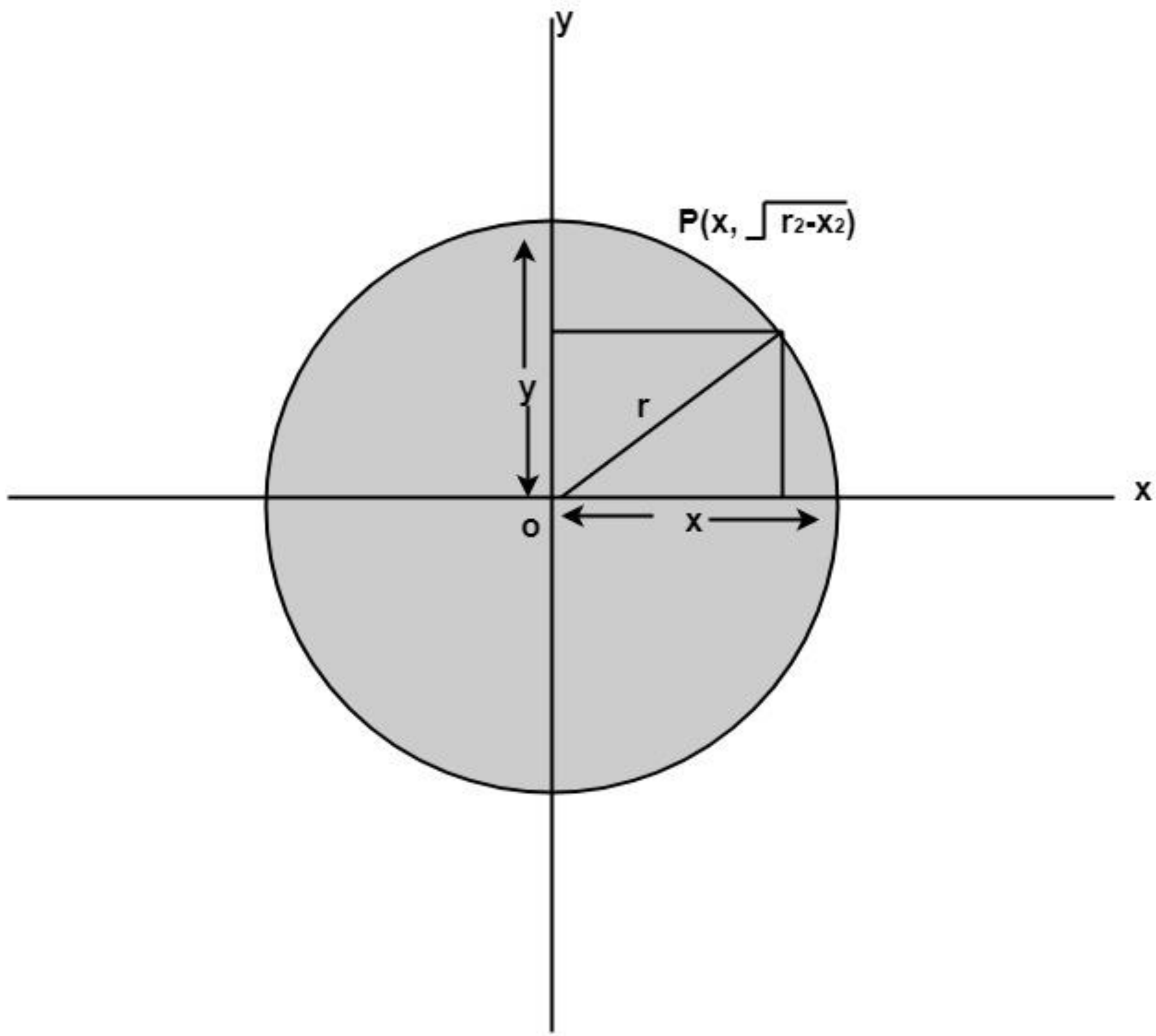
Defining circle using Polynomial method

- The first method defines a circle with the second-order polynomial equation as shown in fig:
- $y^2=r^2-x^2$

  Where x = the x coordinate

  y = the y coordinate

  r = the circle radius
- With the method, each x coordinate in the sector, from 90° to 45°, is found by stepping x from 0 to $r/\sqrt{2}$ & each y coordinate is found by evaluating $\sqrt{r^2-x^2}$ for each step of x.

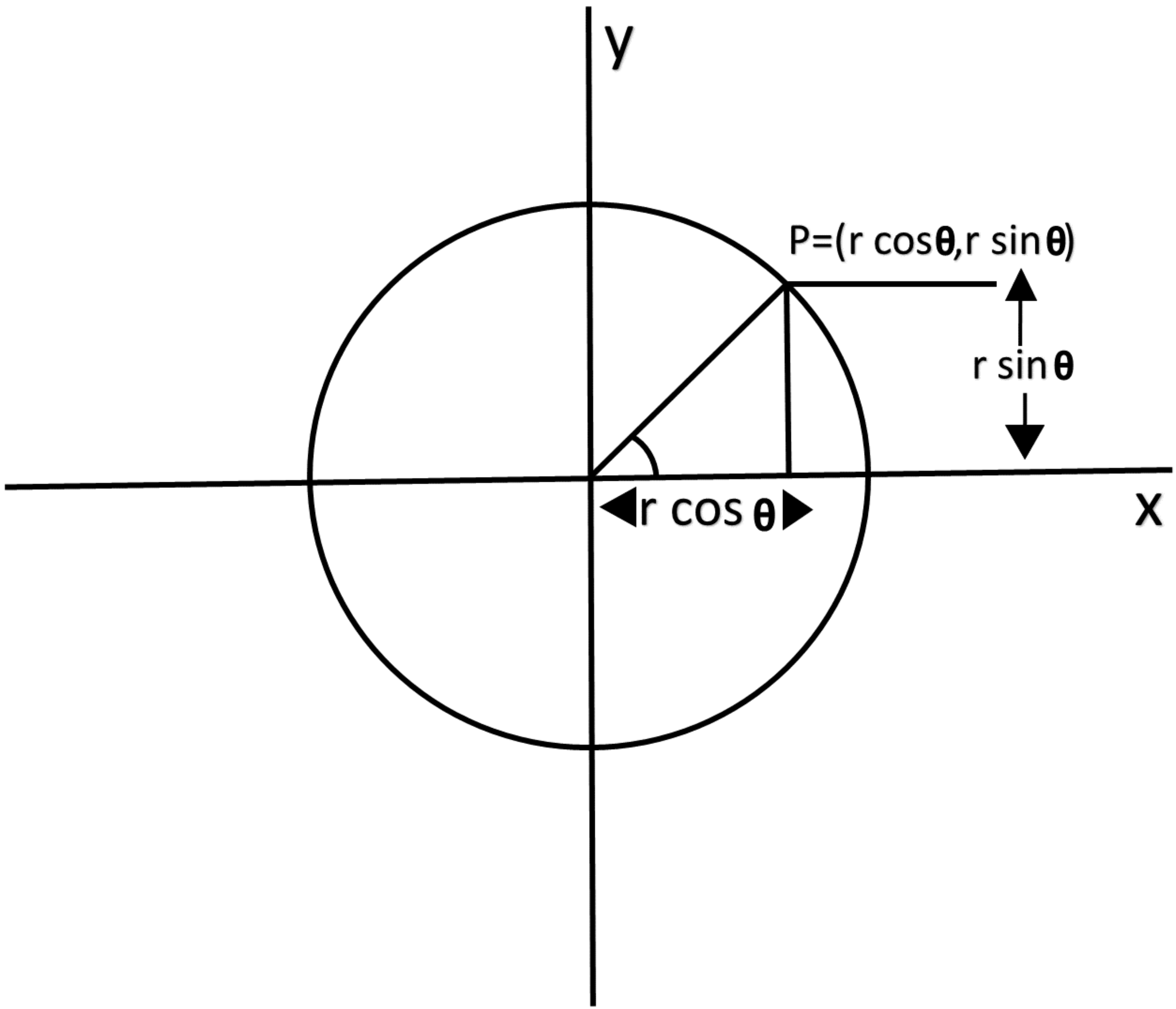


y
P(x, √r2-x2)
y
r
x
o
x

Defining circle using Polar Coordinates

- The second method of defining a circle makes use of polar coordinates as shown in fig:
- $x = r \cos\theta \qquad\qquad y = r \sin\theta$

  Where θ=current angle
  r = circle radius
  x = x coordinate
  y = y coordinate
- By this method, θ is stepped from 0 to $\pi/4$ & each value of x & y is calculated.


y
P=(r cosθ,r sinθ)
r sinθ
r cos θ
x

DDA Circle Drawing Algorithm

- The equation of circle, with origin as the center of the circle is given as: $x^2 + y^2 = r^2$
- The DDA algorithm can be used to draw the circle by defining circle as a differential equation.

$$2x\,dx + 2y\,dy = 0 \qquad \text{where } r \text{ is constant}$$

$$\therefore \quad x\,dx + y\,dy = 0$$

$$\therefore \quad y\,dy = -x\,dx$$

$$\therefore \quad \frac{dy}{dx} = \frac{-x}{y}$$

DDA Circle Drawing Algorithm…

1. Read the radius (r), of the circle and calculate value of ε
2. start_x = 0

   start_y = r
3. x_1 = start_x

   y_1 = start_y
4. do

   { $x_2 = x_1 + \varepsilon y_1$

   $y_2 = y_1 - \varepsilon x_2$

   [x_2 represents x_{n+1} and x_1 represents x_n]

   Plot (int (x_2) , int (y_2))

   $x_1 = x_2$;

   $y_1 = y_2$;

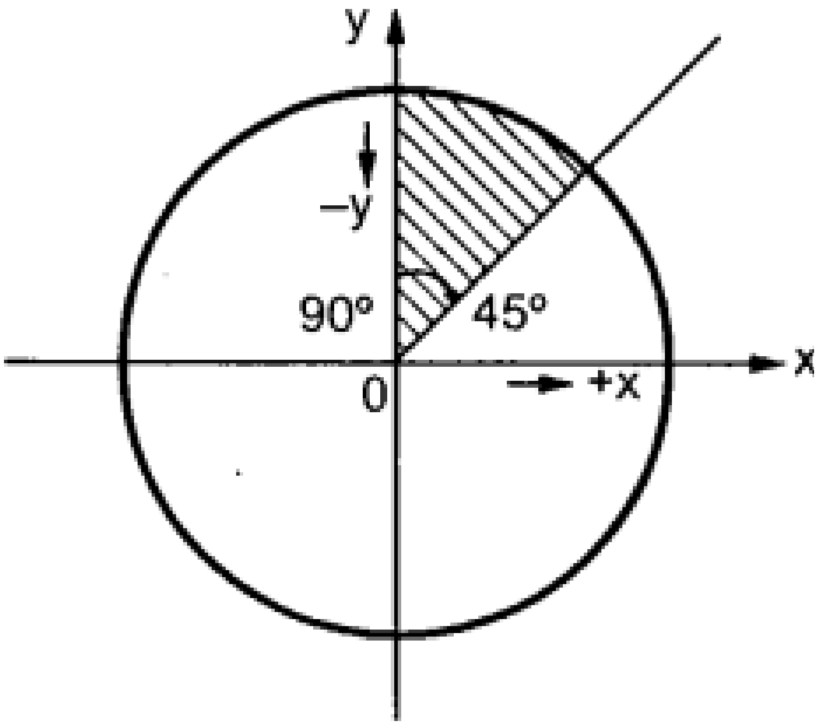
   [Reinitialize the current point]

   } while (y_1 – start_y) < ε or (start_x – x_1) > ε

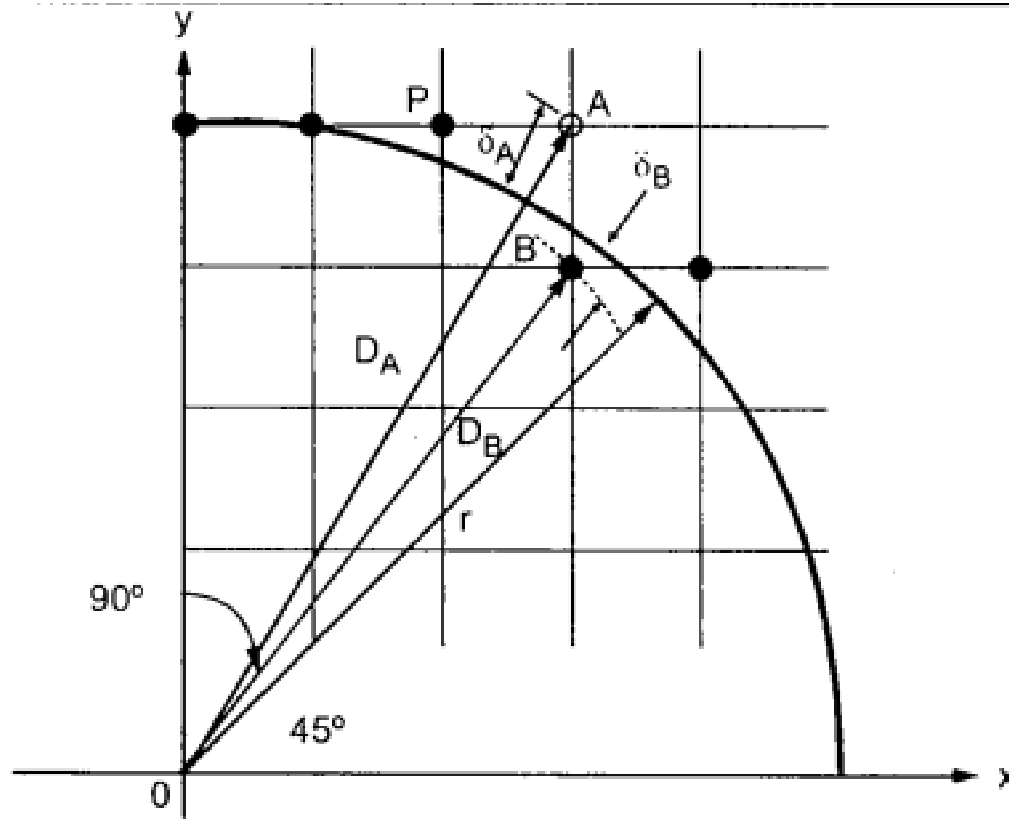
   [check if the current point is the starting point or not. If current point is not starting point repeat step 4 ; otherwise stop]
5. Stop.

Bresenham’s Circle Algorithm

- The Bresenham’s circle drawing algorithm considers the eight-way symmetry of the circle to generate it.
- It plots $1/8^{th}$ part of the circle, i.e. from 90 degree to 45 degree.
- As circle is drawn from 90 degree to 45 degree, the x moves in positive direction and y moves in the negative direction.



y
−y
90°
45°
0
x
+x



y
P
A
δ_A
δ_B
B
D_A
D_B
r
90°
45°
0
x

- To achieve best approximation to the true circle we have to select those pixels in the raster that fall the least distance from the true circle.
- Let us observe the 90 degree to 45 degree portion of the circle.
- It can be noticed that if points are generated from 90 degree to 45 degree, each point closest to the true circle can be found by applying either of the two options:
  - Increment in positive x direction by one unit or
  - Increment in positive x direction and negative y direction both by one unit.

Bresenham's algo. to plot 1/8th of the circle

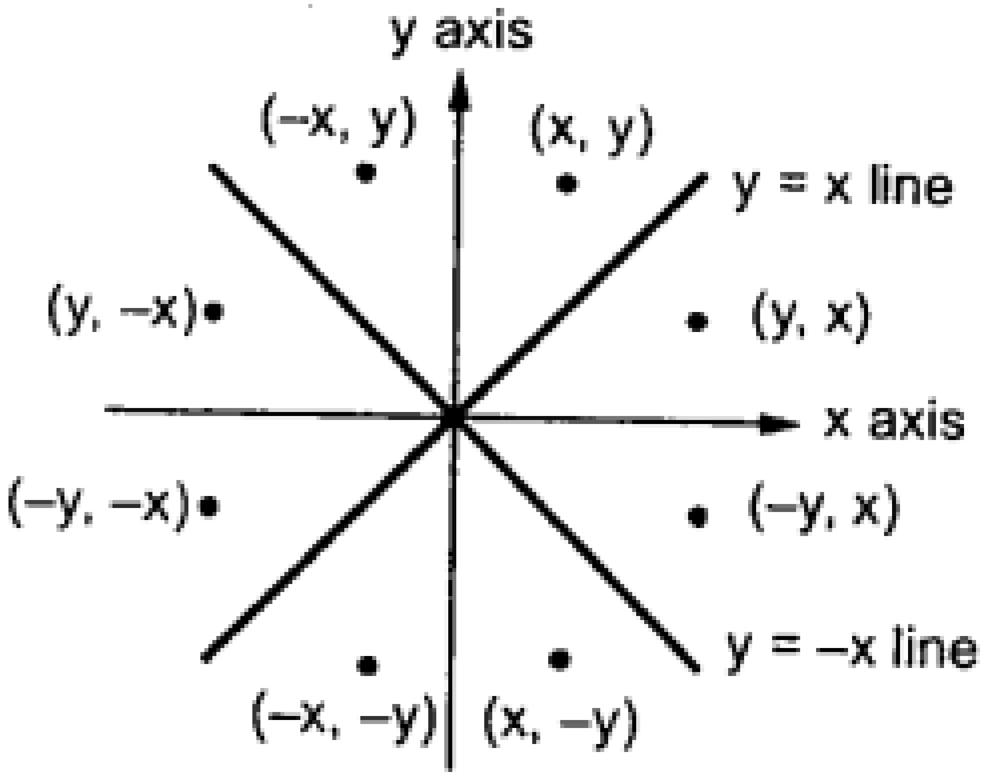
1. Read the radius (r) of the circle.
2. d = 3 – 2 r

   [Initialize the decision variable]
3. x = 0, y = r

   [Initialize starting point]
4. do

```
{
    plot (x, y)
    if (d < 0) then
    {
        d = d + 4x + 6
    }
    else
    { d = d + 4 (x – y) + 10
      y = y – 1
    }
    x = x + 1
} while (x < y)
```

5. Stop



plot (y, x)

plot (y, – x)

plot (x, – y)

plot (– x, – y)

plot (– y, – x)

plot (– y, x) and

plot (– x, y)

Midpoint circle drawing algorithm

- The midpoint circle drawing algorithm also uses the eight-way symmetry of the circle to generate it.

Midpoint circle drawing algorithm…

1. Input radius r and circle center (x_c, y_c), and obtain the first point on the circumference of a circle centered on the origin as

$$(x_0, y_0) = (0, r)$$

2. Calculate the initial value of the decision parameter as

$$p_0 = \frac{5}{4} - r$$

3. At each x_k position, starting at $k = 0$, perform the following test: If $p_k < 0$, the next point along the circle centered on $(0, 0)$ is (x_{k+1}, y_k) and

$$p_{k+1} = p_k + 2x_{k+1} + 1$$

Otherwise, the next point along the circle is $(x_k + 1, y_k - 1)$ and

$$p_{k+1} = p_k + 2x_{k+1} + 1 - 2y_{k+1}$$

where $2x_{k+1} = 2x_k + 2$ and $2y_{k+1} = 2y_k - 2$.

4. Determine symmetry points in the other seven octants.
5. Move each calculated pixel position (x, y) onto the circular path centered on (x_c, y_c) and plot the coordinate values:

$$x = x + x_c, \qquad y = y + y_c$$

6. Repeat steps 3 through 5 until $x \geq y$.

Scan conversion of Ellipse